MAX

3 A

NOVA

(HAVO)|VWO TTO

Physics

NAME AND CLASS:

MALMBERG

NOVA

3 (HAVO)|VWO TTO

Physics

Authors
F. Alkemade
F. Kan
L. Lenders
S. Michon
F. Molin
R. Tromp
P. Verhagen

Final editing
C. Biemans

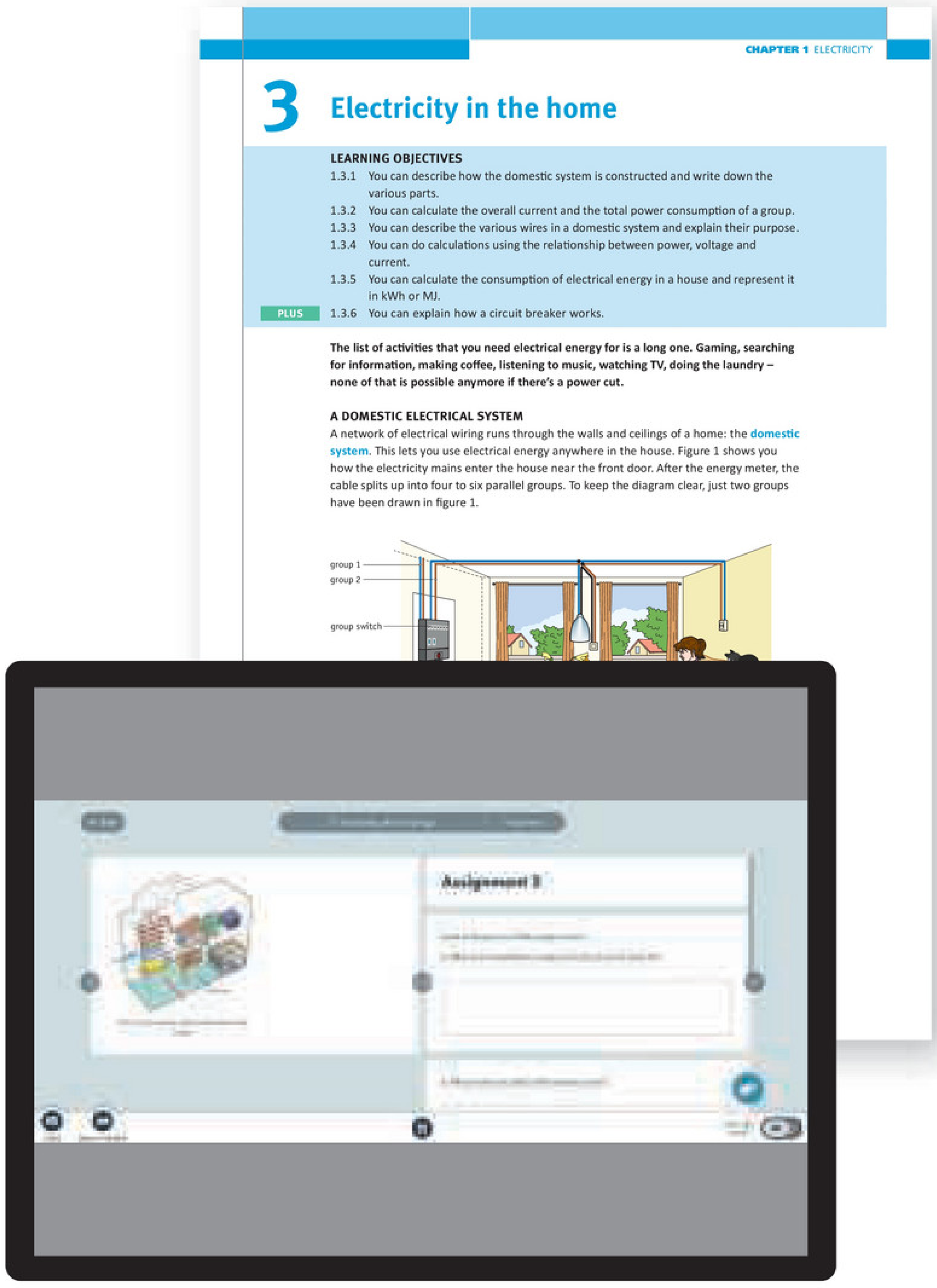
MAX 2020 release

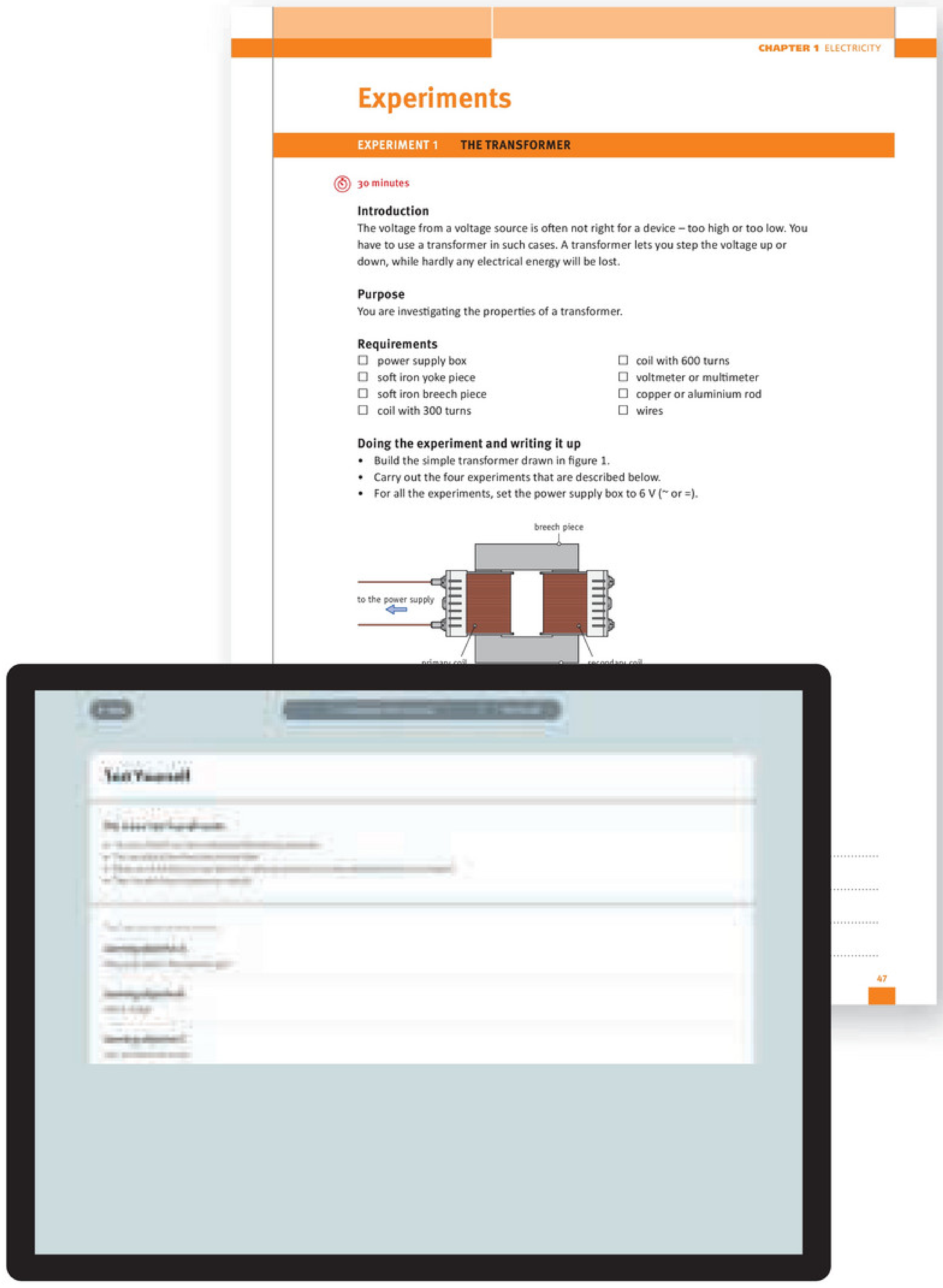
www.malmberg.nl/nova-natuurkunde
Malmberg, 's-Hertogenbosch

Getting started with Nova

Why learn with Nova?

Physics is about the world around you. Nova puts all the tools within easy reach that you need for experiencing, enjoying and discovering it!





Work in your book and work online!

There are two books for each school year plus an online learning environment. Your teacher will decide what you do online (with a laptop, tablet or phone) and what you do in your book. You write the answers to the open exercises in your exercise book, not in your book. Each chapter is split up into an introduction that checks what you already know, theoretical sections and a section with practical experiments, an *Everyday science* article and a closing section. Each section begins by stating the learning objectives that tell you what you will be learning about. The extra material lets you see whether physics would be a good subject for you in the later school years. In the experiments section, you will do assignments and learn how to study and investigate. At the end of each chapter, there is an *Everyday science* section, an article in which part of the course material is discussed in practice in a situation from daily life or from a scientific context. The closing part contains the *Remember* and *Definitions and concepts* sections.

The advantages of working online

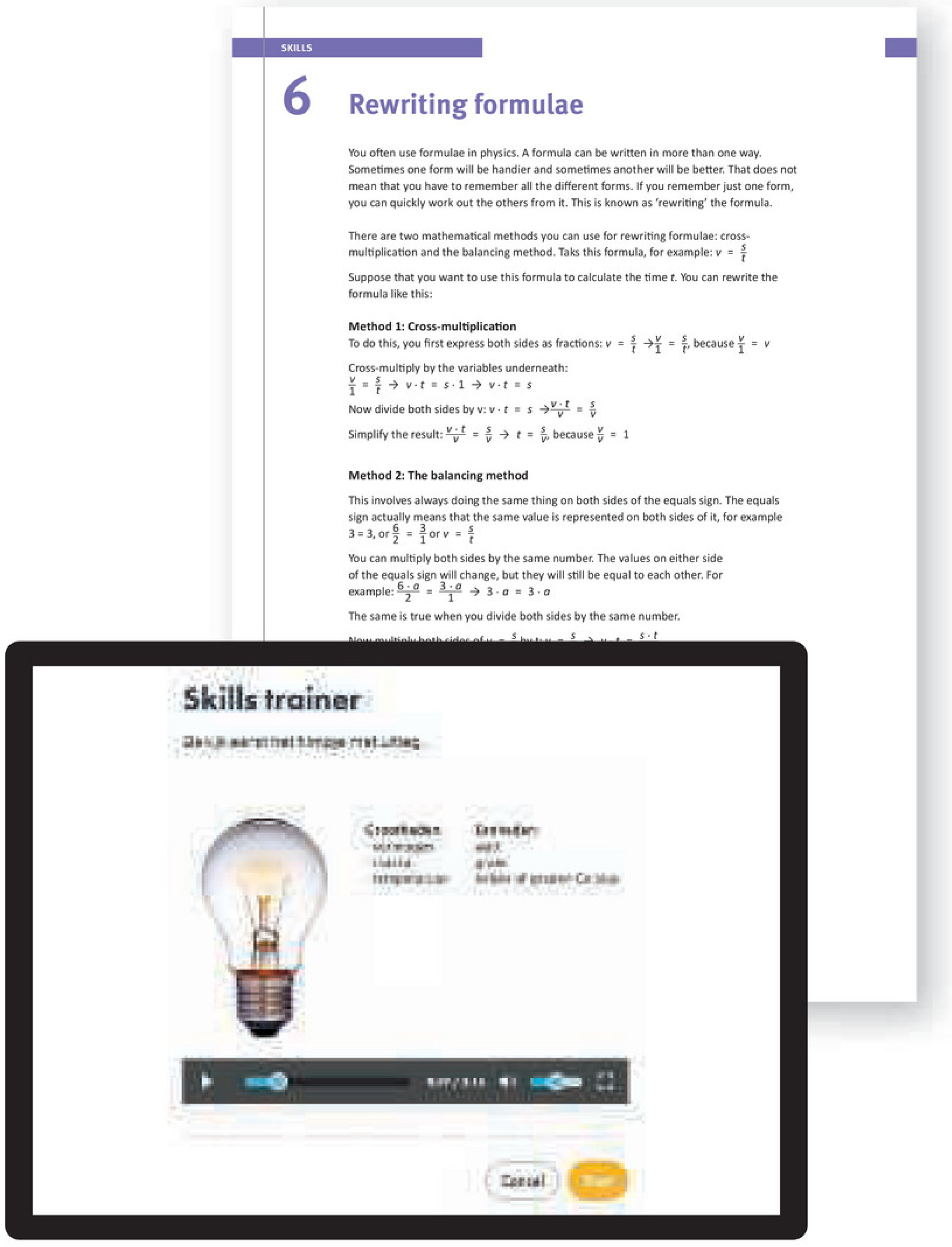
- You will see quickly what you are doing correctly and what you are doing wrong.
- You get feedback on your answers straight away.
- You can watch video clips and animated clips.
- You can practice important skills with the Skills Trainer.
- You learn the concepts using the *Flash cards*.
- You can use the *Test yourself* section, the *Practice test* and the *Diagnostic test* to see how well you have understood the material.
- You can also work with material for a lower level or school year.
- Your teacher will monitor how you are progressing.

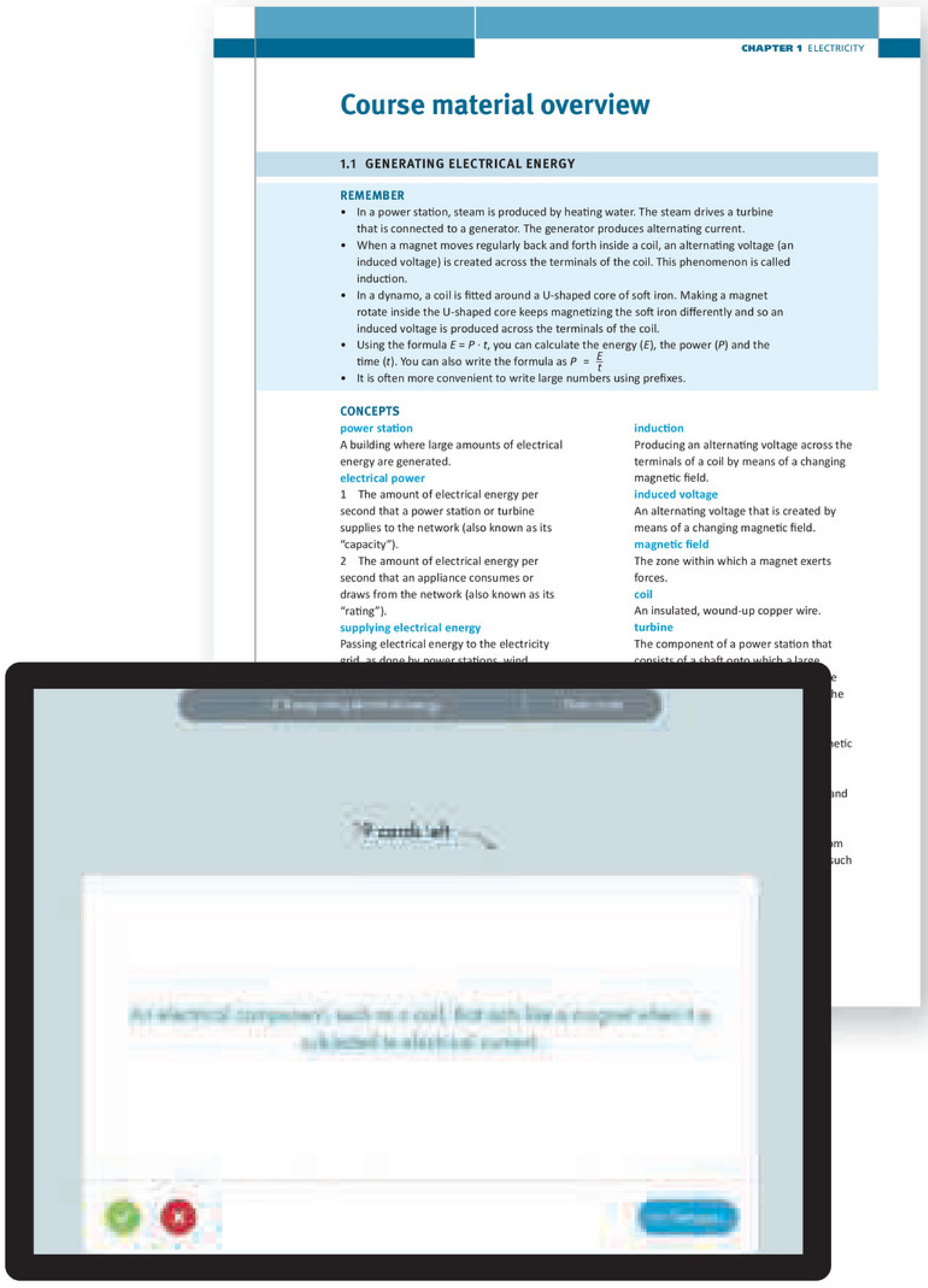
Skills

At the end of each book, you will find a *Skills* section in which the key skills for doing research and investigating are explained. A number of important skills can also be practised online with the *Skills Trainer*.

Good preparation for the test!

The *Remember* and *Definitions and concepts* sections at the end of each chapter in the book will help you prepare for the test. There is a *Diagnostic test* in the *Completion* section online. This is also where you can find the *Flash cards* for learning all the concepts. If you are not sure that you understand the material sufficiently, use the *Test yourself* or *Practice test* parts at the end of each section.





The advantages of the book

- You get a quick overview of what you will be learning.
- You can read the longer texts on paper.
- You can annotate the text and add remarks.
- You write down short answers directly with the exercise.
- You fill in the tables and graphs in the book, just as you do for the results of the experiments.
- You will be making drawings and adding colour yourself, which helps you remember things better.

Meaning of the symbols

Go to the online learning environment for some useful extras.

EXP. 1 There is an experiment for this classroom material.

This is how long this experiment will take.

Use the skills for this assignment.

This assignment is extra challenging.

Contents Part A

Contents Part B

1

Electricity

USING ELECTRICAL ENERGY

Renewable energy sources are the future. You can see solar panels and wind turbines being used more and more for generating electricity. Cars that run on petrol or diesel are increasingly being replaced by electric vehicles. Instead of refuelling at a petrol station, you now find a parking space on the street that has a recharging point.

What do you already know about electricity?

LEARNING OBJECTIVES

1 You can explain what voltages and currents are and how you measure these variables.
2 You can explain what the frequency of a vibration is.
3 You can explain the difference between a parallel circuit and a series circuit.
4 You can do calculations using the units of current, voltage and time.
5 You can explain which substances are conductors and insulators and give a number of examples of them.
6 You know the symbols that you use to make a circuit diagram.

In Parts 1 and 2 of Nova NaSk, you already learned various facts about motion, mass and weight. You will need this knowledge again when you start this chapter. If you want to do a quick check of what you can remember, do the following exercises.

EXERCISES TESTING YOUR PRIOR KNOWLEDGE

1 The circuit in figure 1 uses two meters, 1 and 2. They have been connected correctly.

- Meter .... is an ammeter. You use this to measure the .... in units of ...., for which the symbol is ....
- Meter .... is a voltmeter. You use this to measure the .... in units of ...., for which the symbol is ....

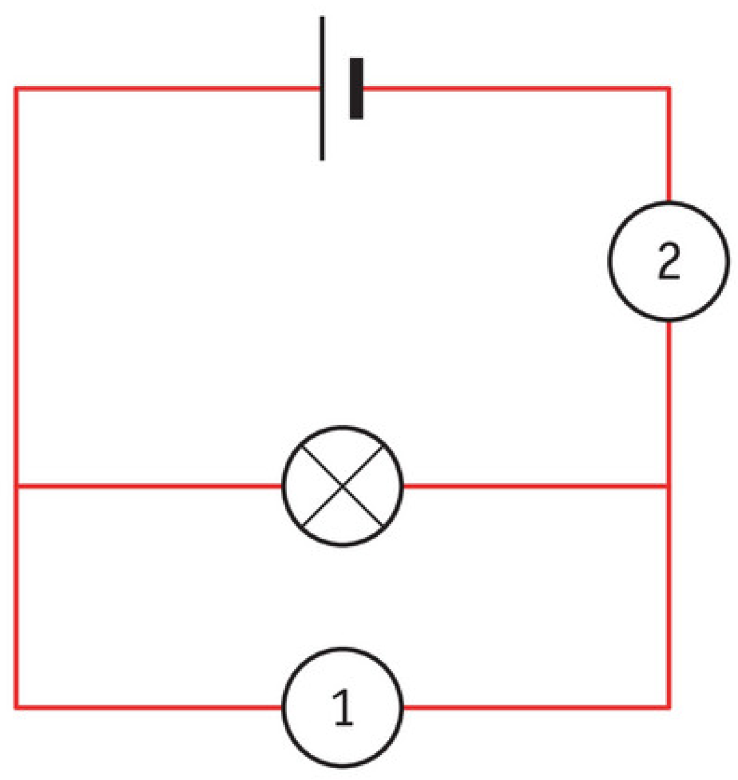


figure 1 A circuit with two meters.

2 Riza's loudspeaker is making an annoying buzzing sound. The cone of the speaker goes in and out fifty times a second.
Which is correct?

○ A The amplitude of the sound vibration is 50 dB.
○ B The amplitude of the sound vibration is 50 Hz.
○ C The frequency of the sound vibration is 50 dB.
○ D The frequency of the sound vibration is 50 Hz.

3 Read off what the voltmeter in figure 2 is showing. Note where the red wire is connected.

U = ... V

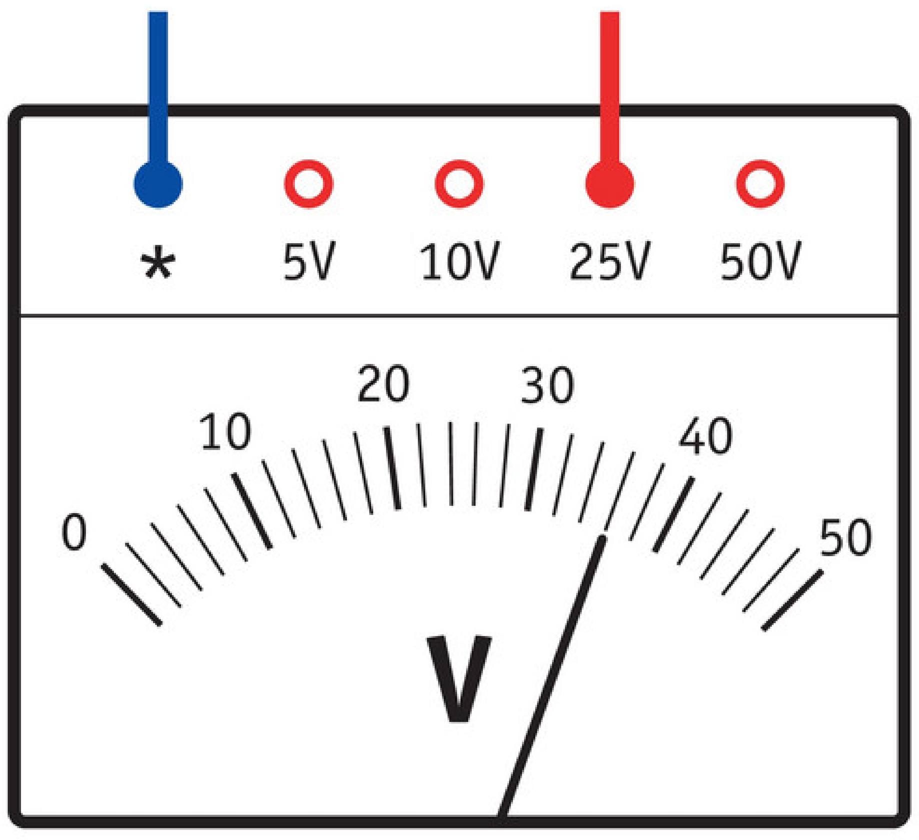


figure 2 A voltmeter.

4 Convert.

275 mV = ... V

0.025 V = ... mV

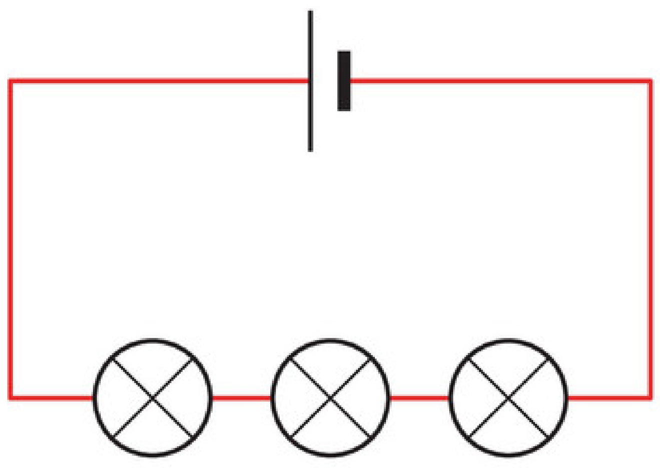
17 mA = ... A

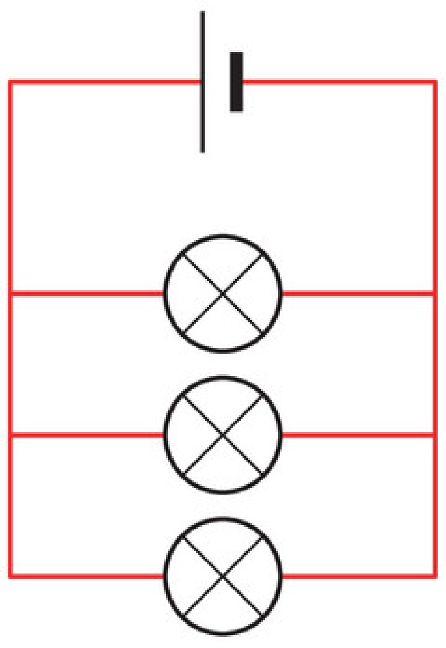
0.734 A = ... mA

45 min = ... h

0.125 h = ... s

5 Write down the type of circuit under each of the figures.





....

6 Underline the materials that conduct electric currents well.
wood / glass / iron / copper / plastic / silver

If you want to know whether you have the prior knowledge you need for this chapter, do the *Prior knowledge test* online. You will also find videos there on the key learning goals for this chapter.

1 Generating electrical energy

LEARNING OBJECTIVES

1.1.1 You can describe the component parts of a power station and say what they do.
1.1.2 You can explain how an induction voltage is generated in a dynamo.
1.1.3 You can explain what is meant by the electrical power (supplied or consumed).
1.1.4 You can calculate the energy consumption of an electrical device in units of joules.
1.1.5 You can use prefixes or powers of ten to express small, everyday and very large amounts of energy in joules.
PLUS 1.1.6 You can do calculations using power, peak wattage and energy.

There are dozens of power stations in the Netherlands (figure 1). They produce a large proportion of the electrical energy that the country's residents need. The contribution made by solar cells and wind turbines is not yet very large in the Netherlands, although it is going to increase a lot over the coming years.

figure 1 The Amer power station in Geertruidenberg.

THE POWER STATION

A **power station** generates electrical energy for many thousands of homes and companies. Figure 2 shows you how a power station works.

1. Large burners burn natural gas, coal or another fuel. The heat that is released heats up the water in a boiler. This creates steam – hot water vapour – at a temperature of approximately 500 °C and very high pressure.
2. The steam passes the blades of a **turbine** at high speed. This makes the shaft of the turbine rotate.
3. A **generator** – a kind of large dynamo – is connected to the shaft of the turbine. Electrical energy is generated in the generator when the turbine shaft rotates.
4. The 'waste' steam, at a much lower temperature and pressure, is passed into a condenser where the steam is cooled down using coolant water so that it condenses back into liquid water. That water can then be pumped back into the boiler, where the cycle begins again.

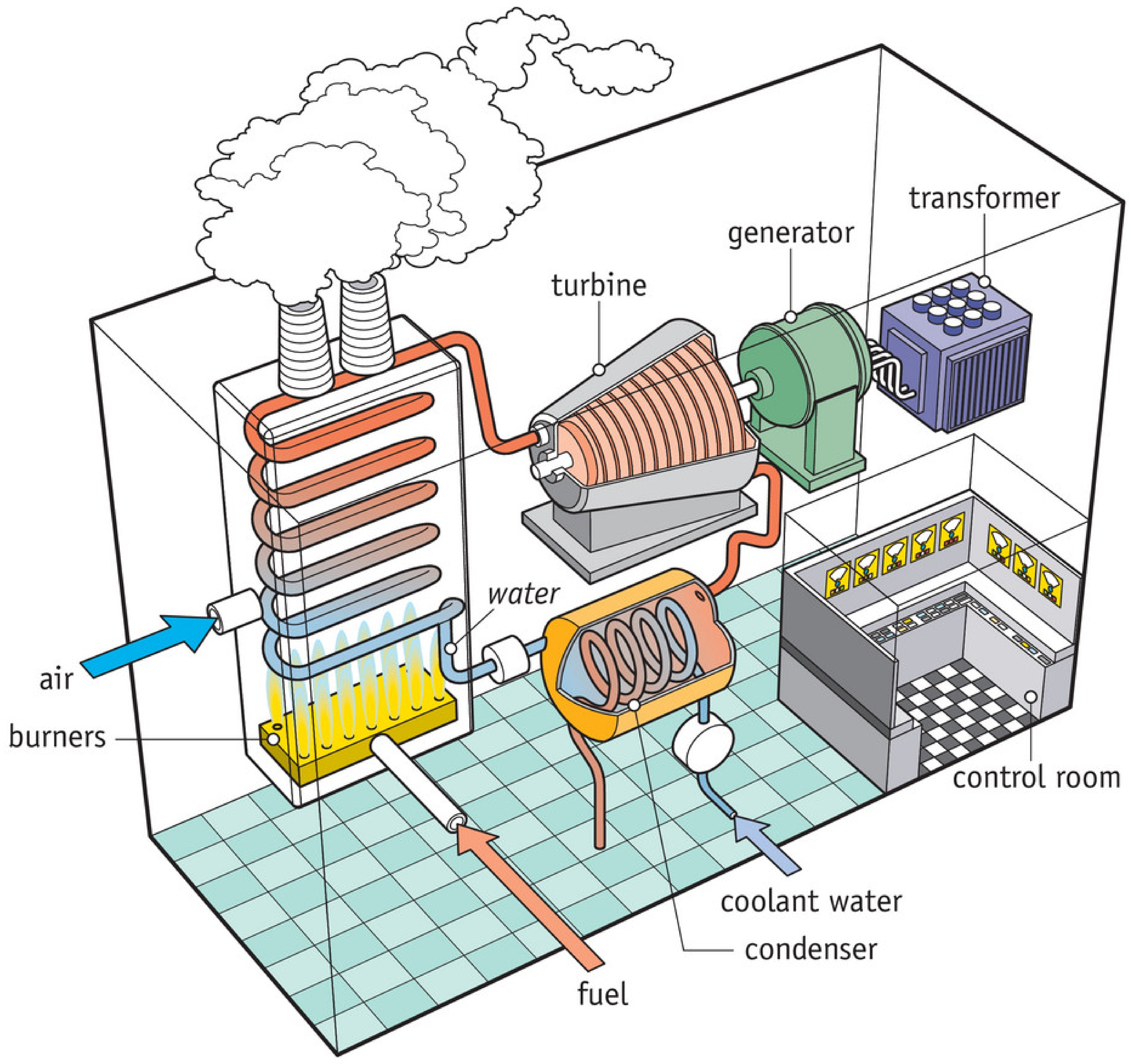


figure 2 This is what a power station looks like on the inside.

The coolant water is usually taken from a river or lake and pumped back into it after it has been used. It has not become polluted but it is quite a bit warmer. If the coolant water is too hot to be discharged straight away, it must first be cooled down in a cooling tower (figure 3). The white 'smoke' that you can see coming out of one of these cooling towers is coolant water that has first evaporated and is then condensing again in the cold air outside.

figure 3 The white 'smoke' from cooling towers is made up of water droplets.

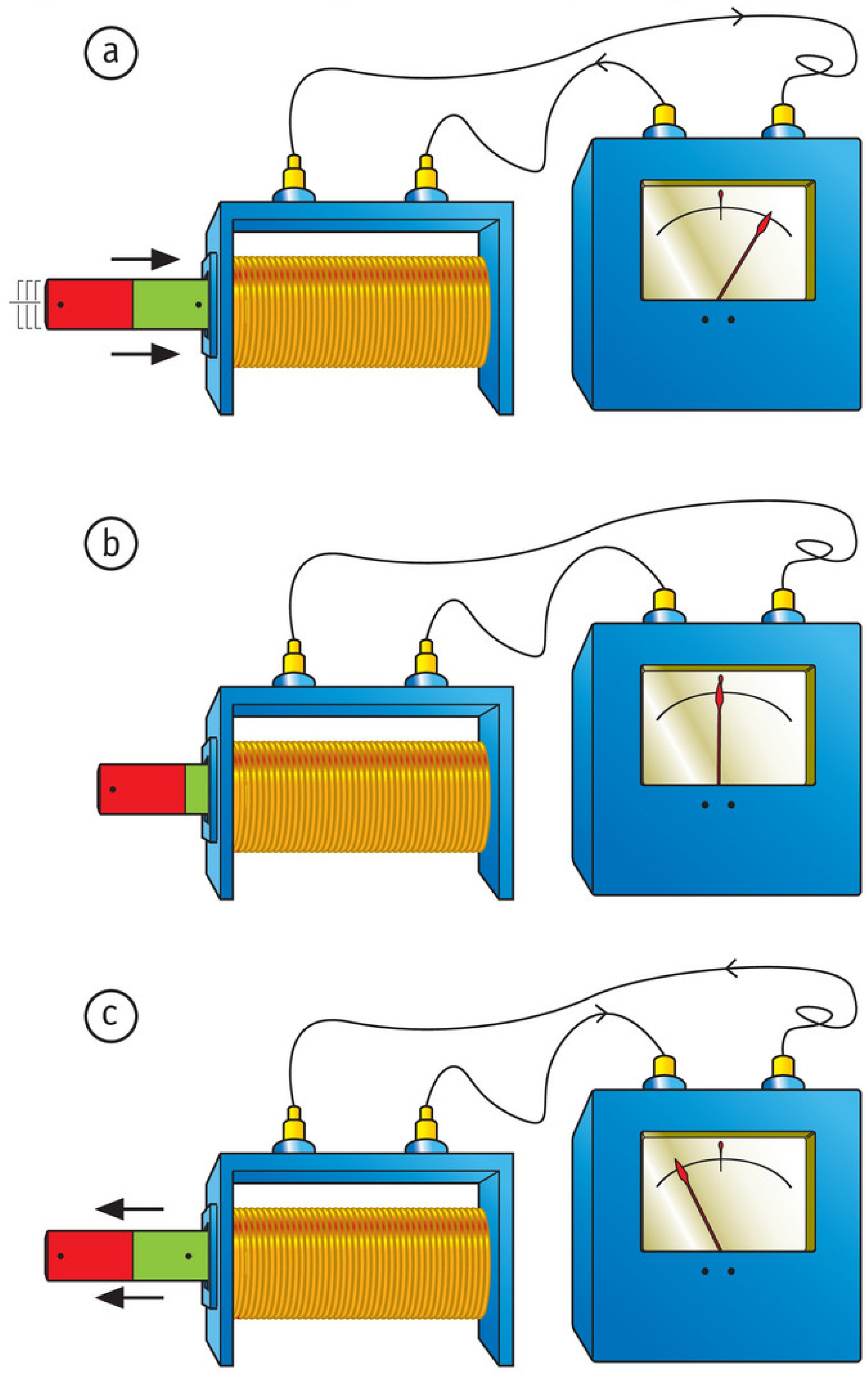
GENERATING AN INDUCED VOLTAGE

The generator in a power station works on the same principle as a bicycle dynamo. They both use motion to create a voltage. Figure 4 shows you an experiment with a simple model of a dynamo. The setup consists of a **coil** (insulated copper wire, wound up), a magnet and a voltmeter.

- In figure 4a, a magnet is being inserted into the coil. The voltmeter needle then moves to the right.
- In figure 4b, the magnet is in the coil but it is not moving. The voltmeter then registers 0 V.
- In figure 4c, the magnet is being removed from the coil. The voltmeter needle now moves to the left.

If you move the magnet regularly back and forth in the coil, the voltage will be changing the whole time. In other words, an **alternating voltage** (a voltage that is always changing) will be generated across the terminals of the coil. This effect is known as **induction**. The alternating voltage that is generated is also known as an **induced voltage**.

figure 4 Generating an alternating voltage using a moving magnet.



The setup shown in figure 4, with a magnet that moves back and forth, is not very practical. A rotating movement is used in a real dynamo. This type of dynamo has been drawn in figure 5. The coil is wound around a U-shaped core made of soft iron. **Soft iron** is a form of iron that you can magnetize and demagnetize quickly. If you put a magnet close to this type of iron, it will quickly become magnetized. If you take the magnet away, the magnetism will be lost just as quickly.

If the magnet is rotating, the soft iron will keep being magnetized differently. You can see that from the **field lines** that have been drawn in the core. These lines show the direction of the **magnetic field** (the zone within which the magnet exerts a force). For each revolution of the magnet, the magnetic field going through the coil changes direction twice. This creates an induced voltage across the ends of the coil.

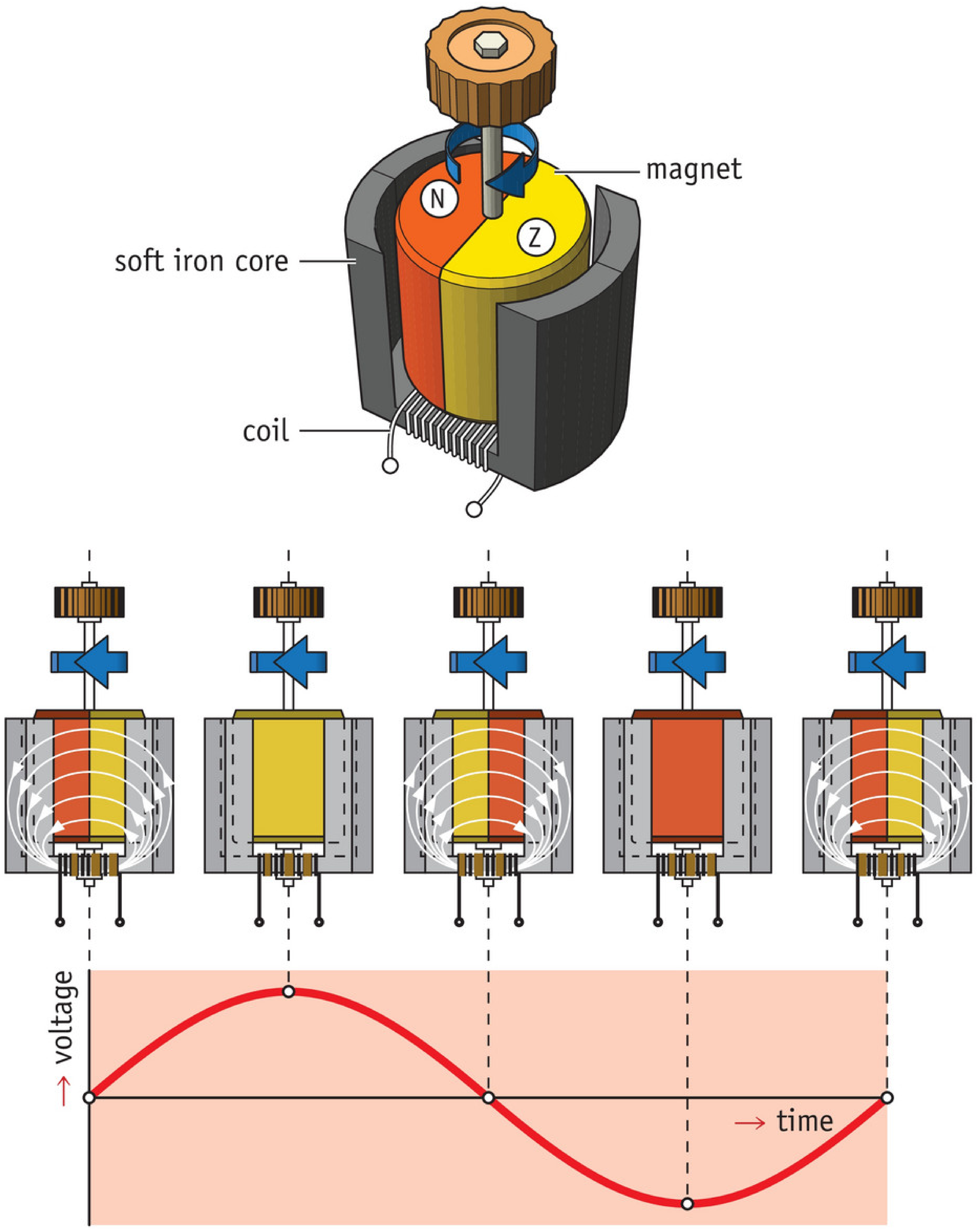


figure 5 This is how an alternating voltage is generated in a dynamo.

ELECTRICAL POWER

Some power stations can **supply** more **electrical energy** in a given time than others. If you want to compare that aspect of the power stations, you have to look at their capacity, their electrical power. The **electrical power** is the maximum amount of electrical energy that the power stations can supply per second. The Enecogen power station in Rotterdam Europoort, for example, has a capacity of 870 megawatts (870 MW). There are even power stations that can supply twice that amount.

Power stations and wind turbines produce electrical energy for devices such as lights, computers, dryers and so forth. We say that these devices **consume electrical energy**. This doesn't mean that the energy completely disappears. One or more other forms of energy always appear instead of the electrical energy. A LED light, for example, consumes electrical energy but produces two other forms of energy in its place: light and heat.

Any electrical device has its own power rating. That is the amount of electrical energy that the device uses per second. A LED light could for example have a power rating of 10 W. Which isn't very much if you compare it to the power output from a power station or a wind turbine. If the wind is blowing hard enough, a single wind turbine of 3.0 MW can provide electrical energy for hundreds of thousands of LED bulbs at once (figure 6).

figure 6 A wind turbine with a capacity of 3.0 MW is about 100 m tall.

CALCULATING THE ENERGY CONSUMPTION

A device with a high power rating does not necessarily have to consume a lot of energy. If you almost never use it, the average energy consumption will be pretty low. Conversely, a device that uses very little power may consume an unexpectedly high amount of energy if it is left on night and day. So the energy consumption of an appliance depends on its power and the length of time it is in use. Expressed as a formula:

$$E = P \cdot t$$

where:

- E is the energy in joules (J);
- P is the power in watts (W);
- t is the time in seconds (s).

You can also write this formula as:

$$P = \frac{E}{t}$$

If you divide the energy consumption in joules by the time in seconds, you will get the power in watts. In other words, 1 watt is the same as 1 joule per second (1 W = 1 J/s). So you can say that an electrical device has a power of 10 watts, or that it consumes 10 joules of electrical energy per second. That sounds like two different things, but they are saying the same.

EXAMPLE EXERCISE 1

The LED lamp in figure 7 lights up for 2.0 minutes when the sensor in the lamp detects a movement.
Calculate the energy consumption of the light (in kJ).

given p = 10 W
t = 2.0 min = 120 s

required E = ?

working $E = P \cdot t = 10 \times 120 = 1200$ J = 1.2 kJ

figure 7 A 10 W LED light with a sensor.

MEASURING ENERGY IN JOULES

As you can see from Example Exercise 1, one joule is a very small amount of energy. With 1 joule of electrical energy, you can for example:

- light a bulb of 1 watt for one second;
- lift an object weighing 100 grams by about 1 metre;
- raise the temperature of 1 gram of water by about 0.24 °C.

Electrical devices generally use much larger amounts of electrical energy. Quantities of those magnitudes are better expressed in kilojoules (kJ) or megajoules (MJ). These are more useful sizes for measuring these amounts. For instance, the battery of a smartphone contains 15 to 25 kJ of electrical energy when it is fully charged. And a family of four consumes 45 MJ of electrical energy on average per day.

The electrical energy produced by a power station in a week or a year is much greater still. In calculations, the easiest way of representing such large quantities is by using powers of ten, as in Example Exercise 2. You can also write the answer using a prefix if you want: $32 \cdot 10^{14}$ J = 3.2 PJ (petajoules). See the skills sections on *Working with variables and units* and *Working with powers of ten*.

EXAMPLE EXERCISE 2

The Enecogen power station (capacity 870 MW) ran at an average of 60% of its full capacity in the week of 7-13 October.
Calculate how much electrical energy this power station supplied in that week (7.0 days).

given P = 60% of 870 MW = 522 MW = $5.22 \cdot 10^8$ W
t = 7.0 days = $6.05 \cdot 10^5$ s

required E = ?

working $E = P \cdot t = 5.22 \cdot 10^8 \times 6.05 \cdot 10^5 = 32 \cdot 10^{14}$ J

PLUS SOLAR PANELS

More and more electrical energy is being produced close to home instead of in power stations. That's why you are seeing increasing numbers of solar panels on the roofs of houses and companies (figure 8). That means that less and less fossil fuel is being used and there is no need to transport electrical energy over large distances.

A solar panel converts radiant energy from the sun into electrical energy. The number of solar panels that you need for covering your own electricity requirements (an average of about 10 GJ per year per household in the Netherlands) depends for instance on the power that the solar panels can supply. There is an international agreement that the capacity of a solar cell is given as a **peak wattage** or **Wp** for short. The peak wattage is the electrical power supplied by a solar panel when the light strikes it perpendicularly at an intensity of 1000 W/m^2 and when the temperature of the solar panel is 25 °C. In calculations, you can often assume that this is the maximum power that the solar panel can supply. For an ordinary solar panel, the rule of thumb is that you need roughly fifteen of them to supply the electrical energy needed by an average household.

figure 8 A house with solar panels on the roof.

Practice the concepts using the *Flash cards*.

COURSE MATERIAL

1 Answer the following questions.

a You can generate an alternating voltage using a dynamo.

This kind of alternating voltage is also known as an ....

b The coil in a dynamo is fitted around a U-shaped metal core.

This metal core is made of ....

c Why is this metal used?

d What is meant by the 'magnetic field' of a magnet?

2 Look at the picture of the power station in figure 2.

a What is the heat that is produced by the burners used for?

b What makes the shaft of the turbine rotate?

c What is the name for the device that is used for producing electricity from motion?

d Why are cooling towers built at some power stations?

IN PRACTICE

3 Stevie is doing the experiment shown in figure 9. The voltmeter needle is deflected when Stevie makes the magnet rotate. He then makes four different modifications to his experimental setup.

Will the voltage change in each of the following cases, and if so, how?

- **a** Stevie makes the magnet rotate faster.
- **b** Stevie makes the magnet rotate in the opposite direction at the same speed.
- **c** Stevie removes the soft iron rod from the coil.
- **d** Stevie replaces the magnet with a stronger one.

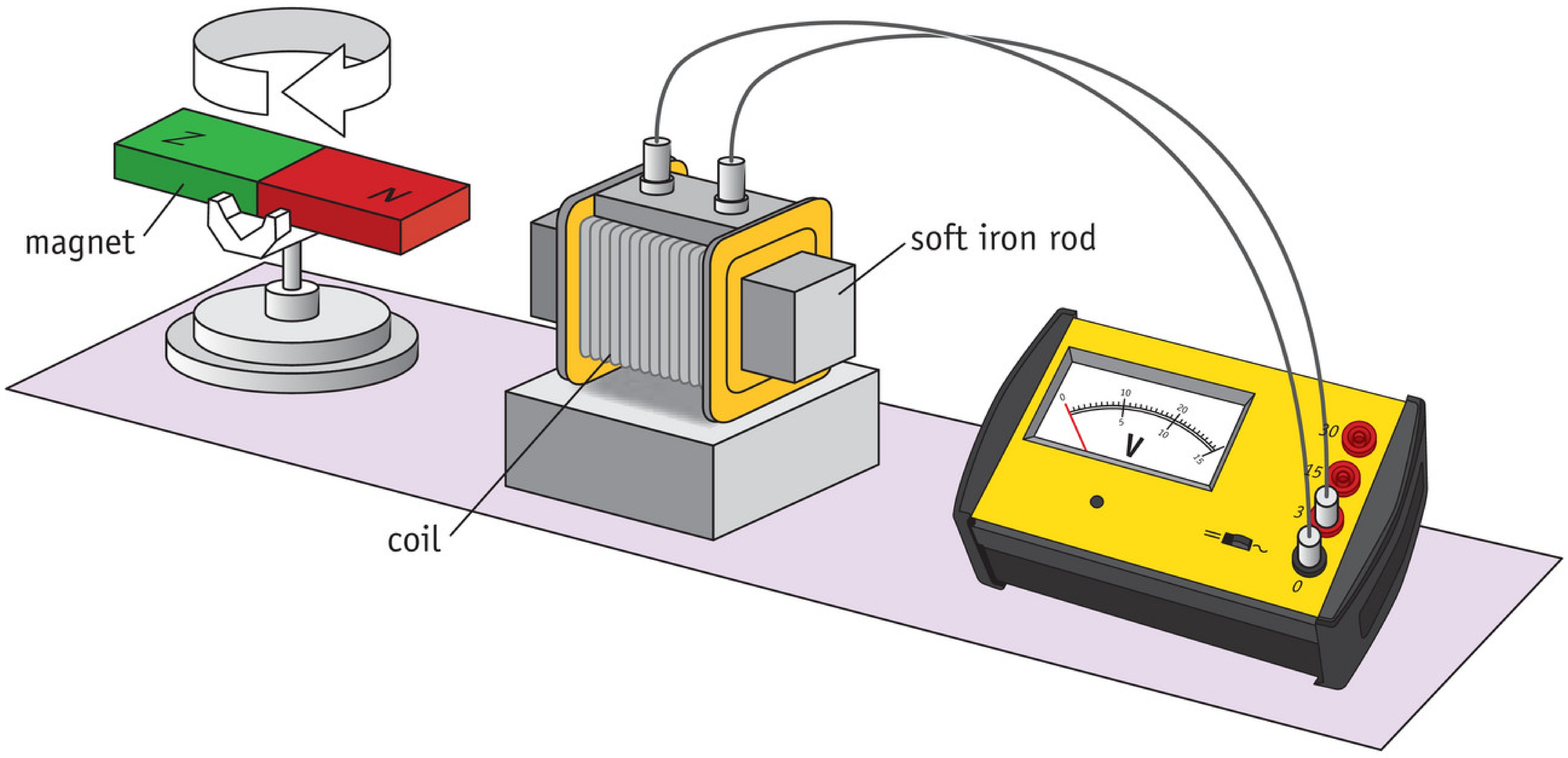


figure 9 Stevie's experiment.

4 Jez's bike has a dynamo in the hub of the front wheel. When it gets dark, the light switches on automatically. After a while, Jez gets tired and starts cycling more slowly. In what two ways does the voltage provided by the dynamo change?

5 The Hemweg coal-fired power station in Amsterdam produces a peak power output to the electricity grid of 630 MW. The Wieringerwerf wind farm provides a peak power output of 300 MW. An average household uses 800 W of electrical power on average during the hours that the electricity consumption is at its peak.

- **a** See the skills section on *Working with variables and units*.
  Calculate how many households can be supplied with electrical energy by the Hemweg power station and the Wieringerwerf wind farm.

If you need more practice in *Calculating electrical power*, go to the *Skills Trainer*.

- **b** Most power stations operate way below their peak output capacity during most of the day.
  Explain why.
- **c** Most wind farms operate way below their peak output capacity during most of the day.
  Explain why.

6 Figure 10 shows the electrical power that an average household consumes over the course of a 24-hour period. One graph is for the summer and the other is for the winter.

a Which line is for the winter? Explain your answer.

b How big is the difference between the maximum and minimum power consumed during the winter?

c Explain why this is a problem for electricity production and think up a possible solution for it.

d Make an estimate of the average power consumption during the winter.

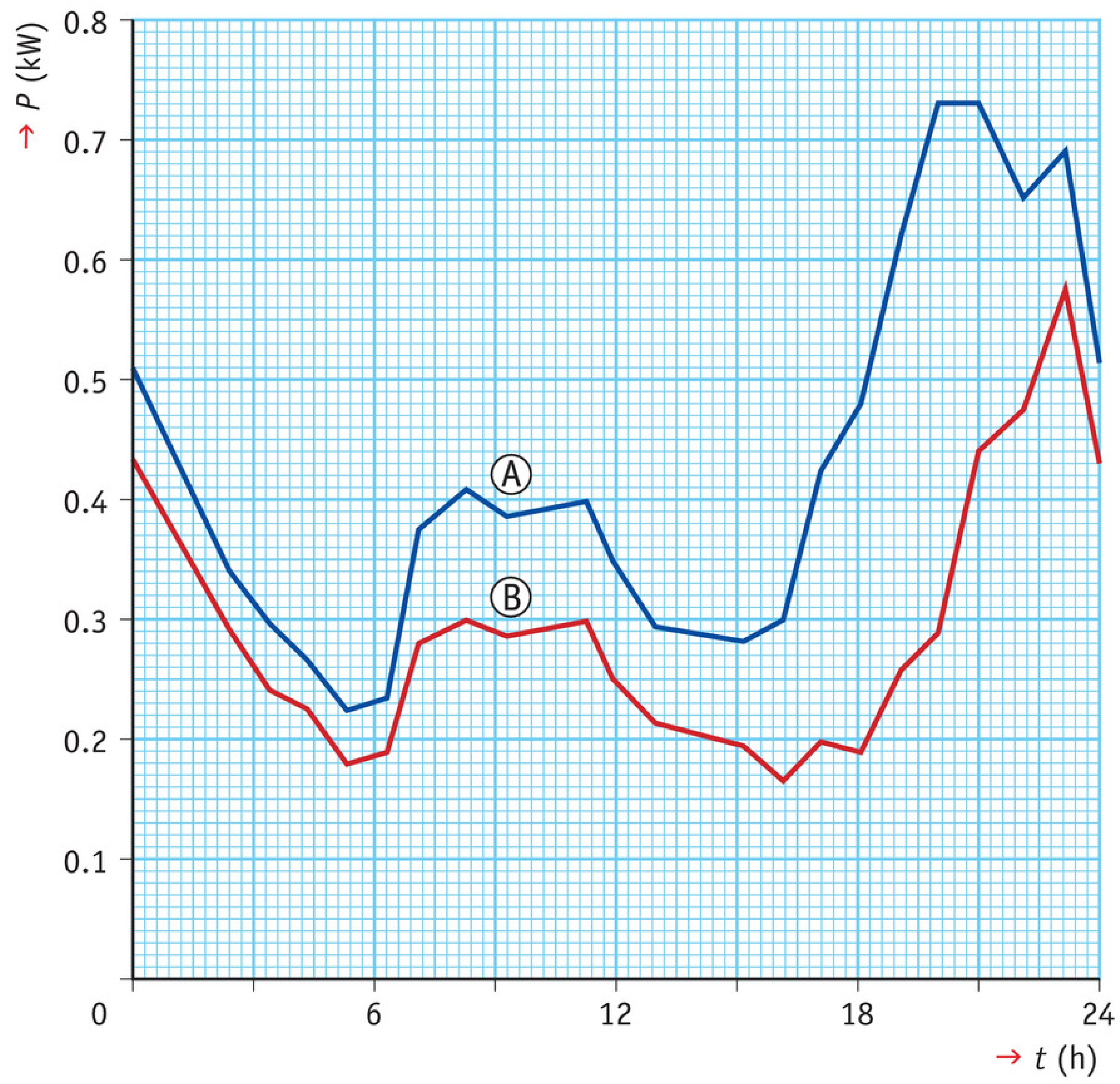


figure 10 The power consumption of an average household.

7 Figure 11 shows you a cross-section of the head of a wind turbine.

a Explain step by step how the wind turbine supplies electrical energy.

b Why is a gearbox needed?

c Does a wind turbine generate an alternating current or a direct current (DC voltage)?

d How does the frequency change if the wind turbine goes round faster?

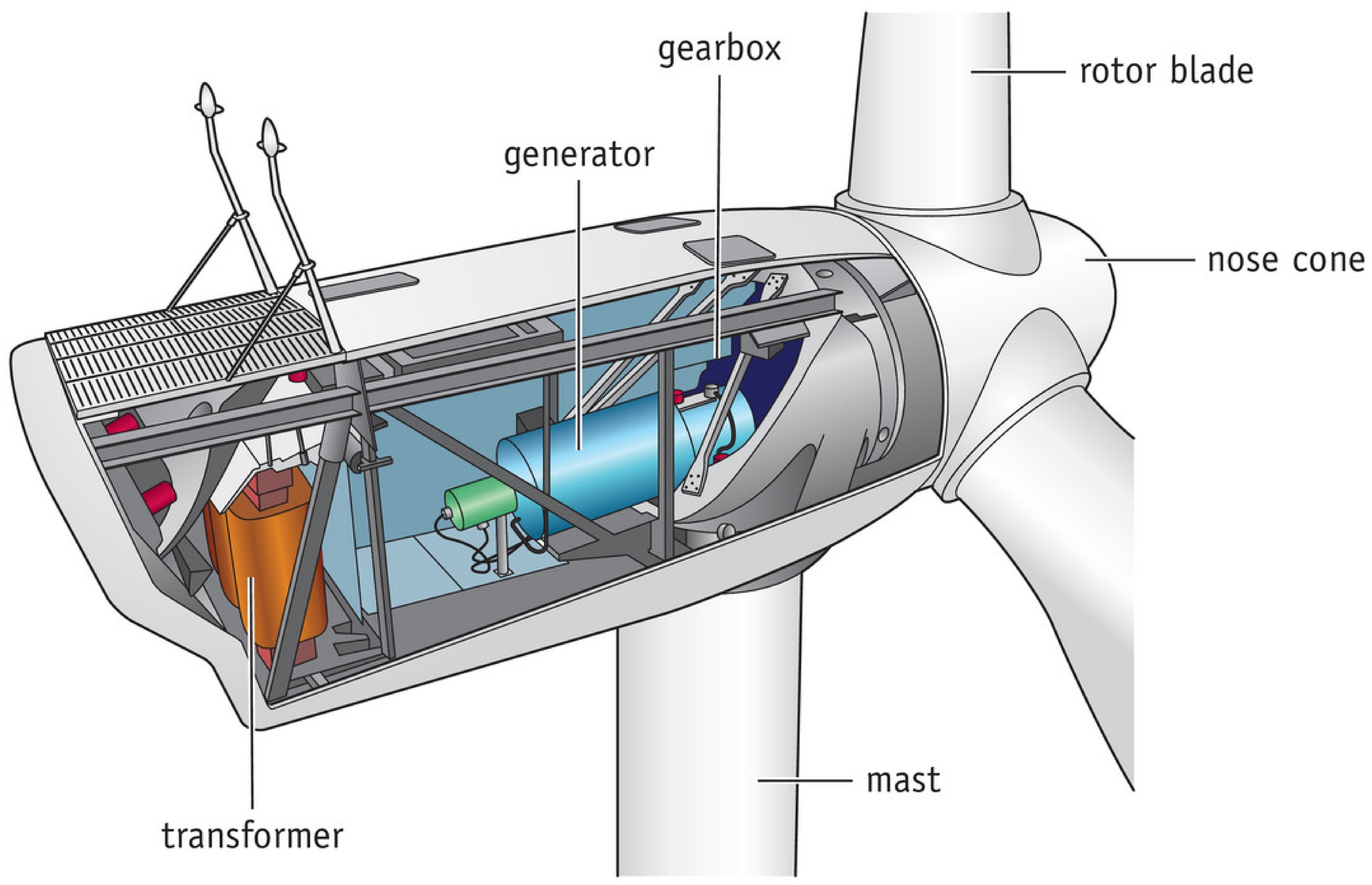


figure 11 The head of a wind turbine.

8 A coffee pad machine is a quick way of making a cup of coffee. This machine heats the right amount of water first. After that, it forces the hot water under high pressure through a coffee pad. Figure 12 shows you how the power consumption goes up and down as it does that.
Using the data in figure 12, calculate how much electrical energy is required to make one cup of coffee.

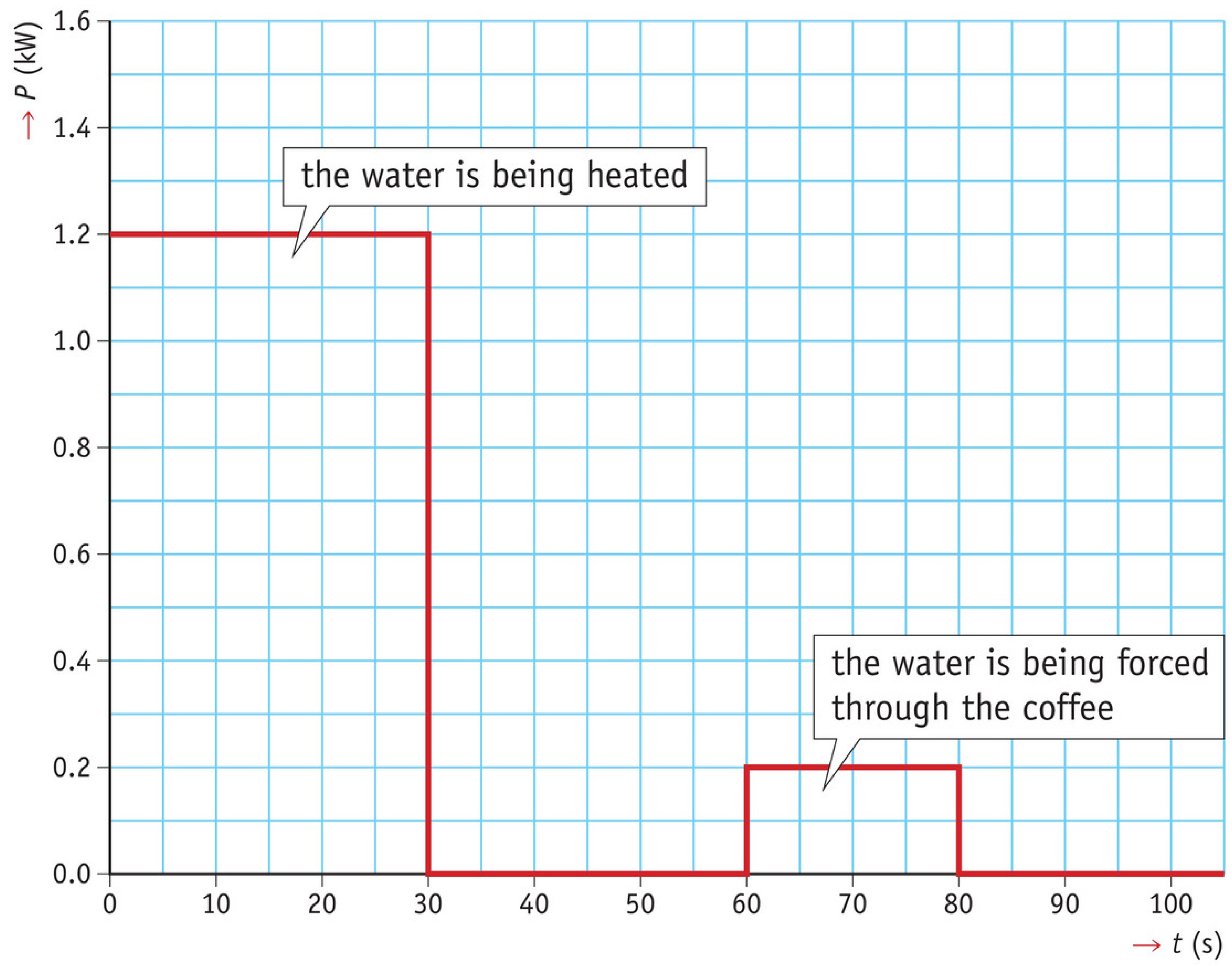


figure 12 The (P,t) diagram of a coffee pad machine.

Test what you know with *Test yourself*.

PLUS SOLAR PANELS

9 You need 1.8 GJ for producing, transporting and recycling a solar panel of 1.0 m^2. After a certain time, that solar panel will have supplied the same amount of energy. Only then will the solar panel have become a net energy producer.

a In the Netherlands, an ordinary solar panel supplies 16.2 W/m^2 on average (day and night).
Calculate how many joules the panel supplies every year.

b Calculate how many years it is before the panel has become a net energy provider.

10 Emily wants to put solar panels on the roof of her holiday home. The output depends not only on the number and type of solar panels but also their orientation (facing south is best) and the pitch of the roof (the angle of slope). The solar panel manufacturer sends her an information brochure giving details of the radiant energy from the sun at her holiday spot (figure 13).

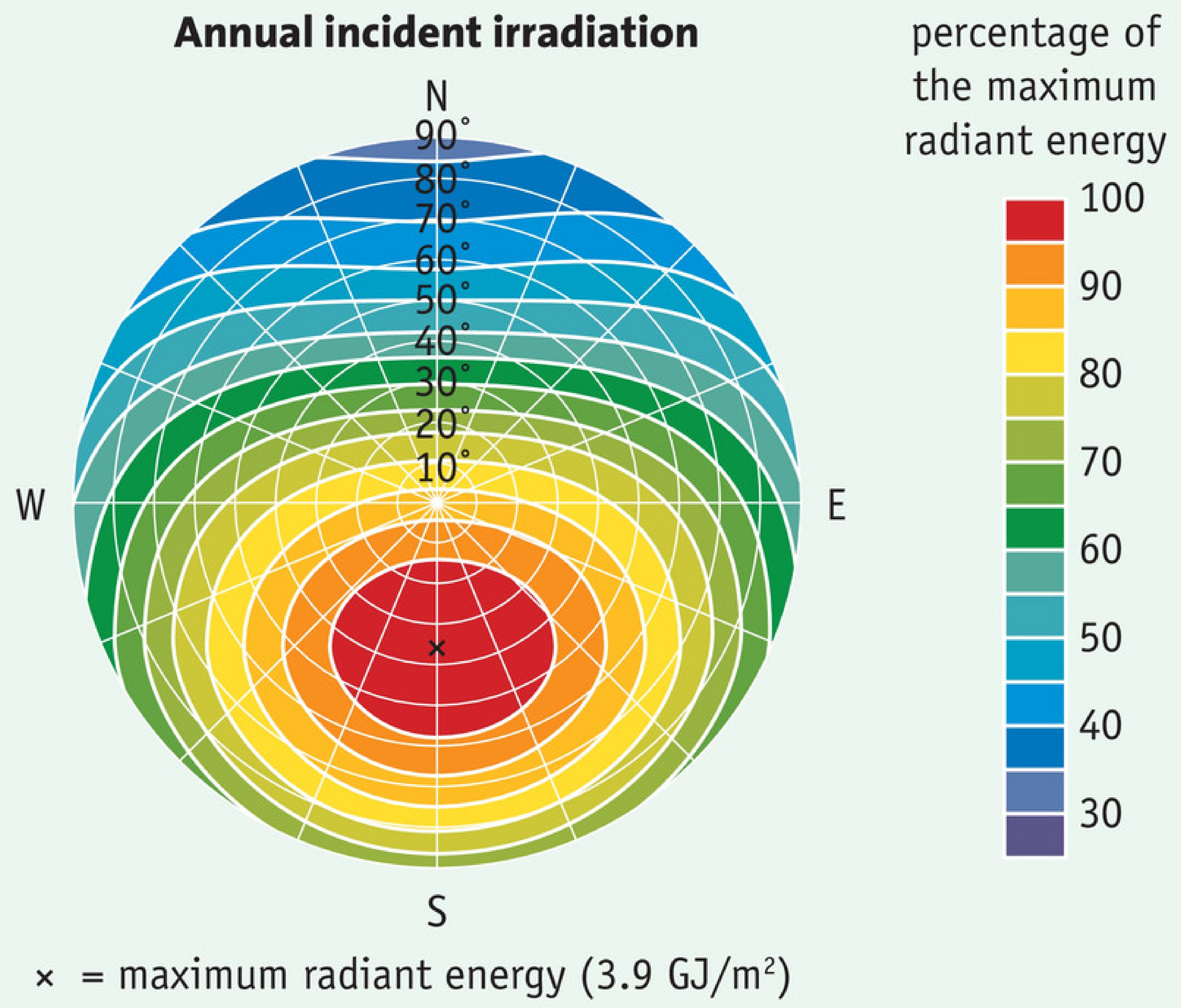


figure 13 Irradiation from the sun per year as a function of the direction and the angle of slope.

a Use figure 13 to help explain what pitch angle of the roof is the most favourable if Emily's solar panels are facing precisely southwards.

b Emily's roof faces precisely east and its pitch is 30°.
Show that 1 m^2 of solar panelling receives about 3.3 GJ of radiant energy per year.

c Emily wants to order solar panels with a capacity of 275 Wp and a surface area of 1.6 m^2. Only part of the incoming radiant energy gets converted into electrical energy. Show that Emily's solar panels convert 17% of the incoming radiant energy into electrical energy under optimum conditions. Use the definition of peak wattage from the text for this.

d In reality, Emily gets an average of 15% of the incoming irradiation per year (3.3 GJ/m^2) converted into electrical energy. Emily uses an average of 10 GJ of electrical energy each year.
Calculate how many solar panels Emily would have to install in her holiday home to meet her whole energy requirement.

e Emily reads the following information on a website:

What is peak wattage again?

The peak wattage (Wp) says how much power the solar panels can produce in the best situation. Reality is always different, of course, so you need to convert the numbers. In the Netherlands, 1 Wp produces about 3.1 MJ each year.

Source: www.essent.nl

Use the data from the website to recalculate how many solar panels Emily would have to install in the Netherlands to meet her own energy needs. Does this answer match the one you found in Exercise d (roughly)?

2 Transporting electrical energy

LEARNING OBJECTIVES

1.2.1 You can explain why the electricity grid uses a variety of voltages.
1.2.2 You can state the features of the mains voltage supplied by the domestic mains and explain them.
1.2.3 You can explain how a transformer steps voltages up or down.
1.2.4 You can use the number of turns in the coils to calculate how a transformer steps the voltage up or down.
1.2.5 You can calculate the primary and secondary currents and voltages for an ideal transformer.
PLUS 1.2.6 You can do calculations involving current, capacity and time.

An extensive power grid transports electrical energy from the power stations to the various consumers. The voltage is transformed up and down several times during this transport.

THE ELECTRICITY GRID

When a current passes through a wire, some of the electrical energy gets converted into heat. The **energy loss** is undesirable: it means there is then less energy left over for the end users. This is a particular problem for long-distance connections, which are inevitably needed if you want to get electrical energy to all corners of the Netherlands.

To limit energy losses, electrical energy is best transported at the highest voltage possible. The higher the voltage used, the lower the energy loss as heat that is produced in the power lines. That is why the voltage provided by the generators is transformed upwards at the power station, for example from 20 kV up to a maximum of 380 kV.

The 380 kV high-voltage lines are the main highways of the Dutch electricity grid (figure 1). They connect all parts of the Netherlands together as well as making connections abroad. This makes it possible to trade in energy with other European countries. There are also regional connections that operate at lower voltages of (for example) 220 kV, 150 kV or 110 kV.

figure 1 High-voltage pylons transport electrical energy at high voltages.

The high-voltage grid transports electrical energy to the various distribution stations where the voltage is stepped back down again to 10 kV. After that, the electrical energy is transported to residential areas and industrial sites using underground cables. Each residential area has one or more transformer substations (figure 2). The voltage is transformed down even further there to the **mains voltage** of 230 V. Finally, the electrical energy is transported to the houses.

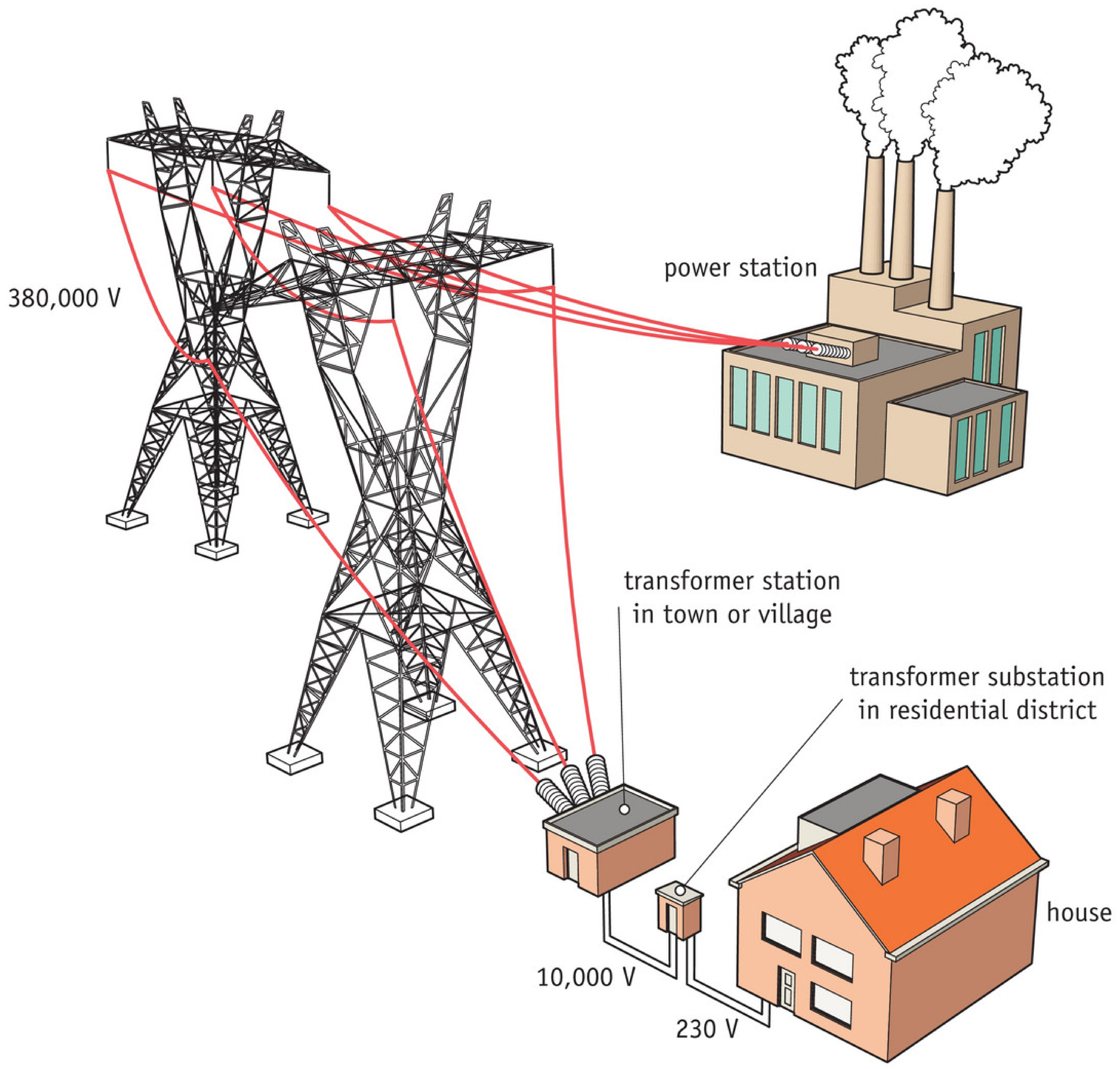


figure 2 The electricity grid takes electrical energy from the power station to the end users.

THE EFFECTIVE VOLTAGE

The mains voltage is continually going up and down in a pattern that repeats fifty times a second: from 325 V via 0 V to −325 V and then back up to 325 V again (figure 3). The mains are at an alternating voltage (or AC voltage) with a **frequency** of 50 Hz. The negative values mean that the **polarity** of the voltage is reversed: the positive has become negative and vice versa.

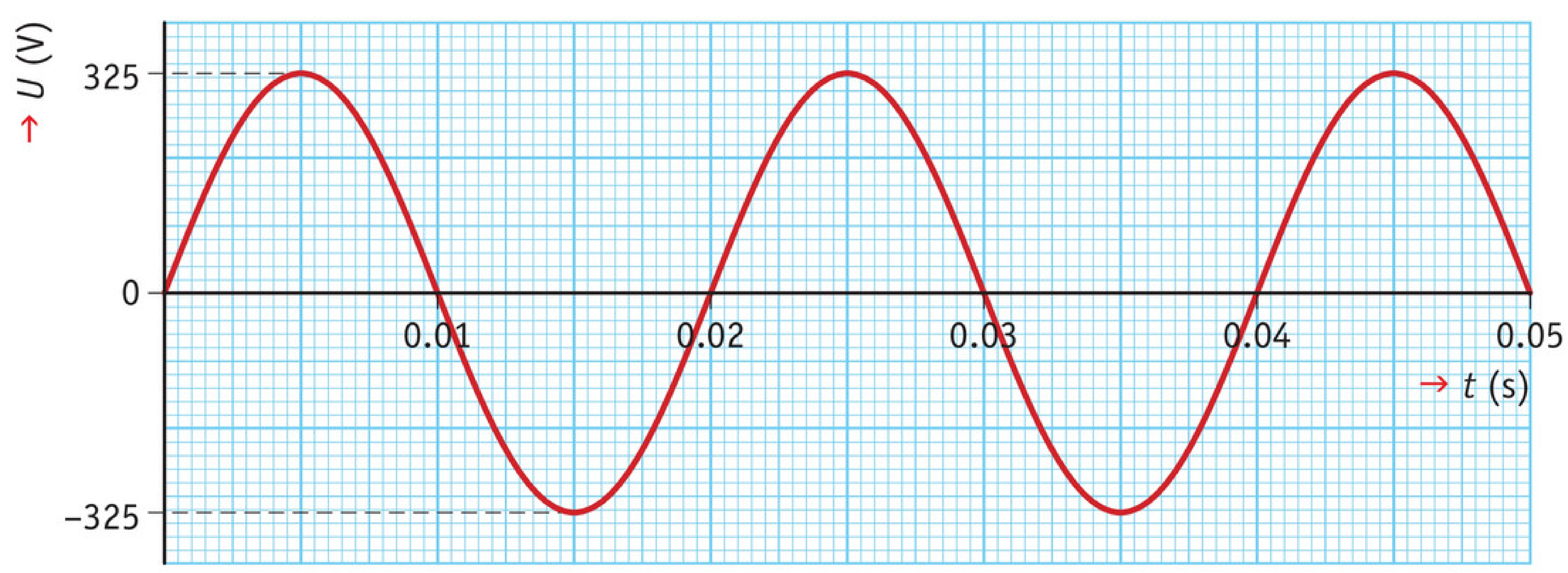


figure 3 An alternating voltage of 50 Hz.

For many appliances, it makes no difference whether they are supplied with the AC voltage of the mains or a direct voltage of 230 V. A kettle, for instance, produces the same amount of heat in both cases. We therefore say that the **effective voltage** of the mains is 230 V. The word 'effective' is almost always left out in practice. Everyone simply says that 'the mains voltage is 230 V'. The high voltages mentioned earlier are all effective voltages too.

The voltage of the mains is too high for many devices, such as a phone or a LED light. These types of devices then need a **transformer** that steps the voltage down even further. That transformer is mostly not a separate device but is instead part of the plug or the bulb.

HOW A TRANSFORMER WORKS

EXP. 1

Figure 4 shows you a simple transformer for home use. The device consists of two coils of insulated copper wire wound around a soft iron core. The **primary coil** is connected to the mains and the **secondary coil** is connected to the appliance.

- When the transformer is being used, an alternating current will go through the primary coil. The primary coil then becomes an **electromagnet**. Because the size and direction of the current are changing all the time, the magnetic field being generated changes too.
- As a result, the soft iron core becomes magnetized. That magnetization changes along with the magnetic field of the primary coil: the direction of the magnetic field flips a hundred times per second, just like the alternating voltage through the primary coil.
- The magnetic field in the secondary coil is therefore also continually changing. This then induces an alternating voltage across the terminals of the secondary coil. This is the voltage that the appliance works on.

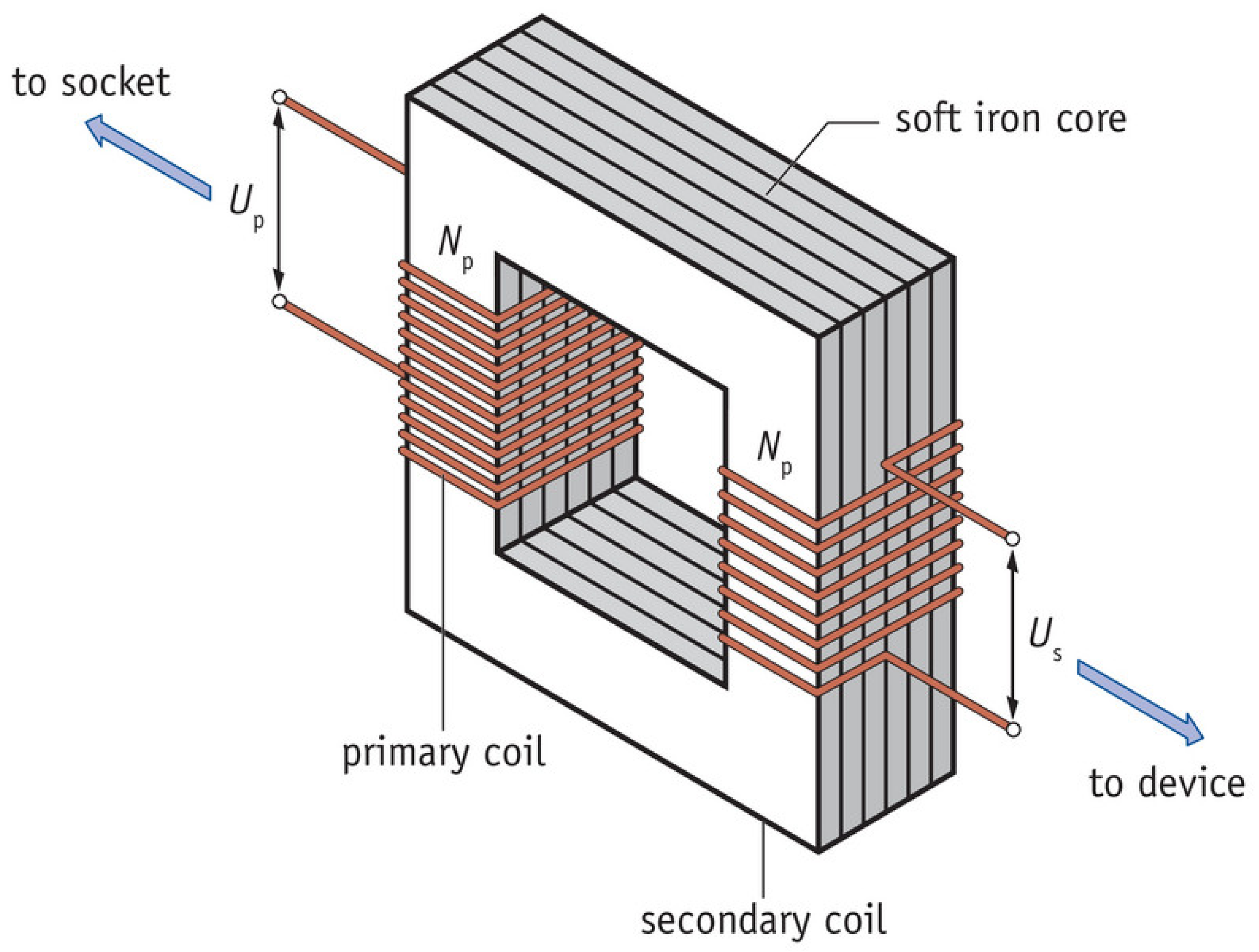


figure 4 A transformer for use in the home (schematic drawing).

The electrical energy put into the primary coil is given out again from the secondary coil. But there is no current running from the primary to the secondary coil. The energy is carried by the magnetic field. The primary and secondary coils are completely isolated from each other, electrically.

STEPPING VOLTAGES UP AND DOWN

You can use a transformer to raise or lower the voltage. How the voltage changes depends on N_p, the number of turns in the primary coil, and N_s, the number of turns in the secondary coil.

- If $N_s > N_p$, the voltage U_s produced by the secondary coil is greater than the voltage U_p of the primary coil: the voltage has been transformed upwards.
- If $N_s < N_p$, the voltage U_s produced by the secondary coil is lower than the voltage U_p of the primary coil: the voltage has been transformed downwards.

The voltages (U_p and U_s) are in the same ratio as the numbers of turns (N_p and N_s). If there are twice as many turns in the secondary coil, the secondary voltage will be twice as high, and so forth. The rule is therefore:

$$\frac{U_p}{U_s} = \frac{N_p}{N_s}$$

where:

- U_p and U_s are the voltages in the primary and secondary coils in volts (V);
- N_p and N_s are the number of turns in the primary and secondary coils. There is no unit for the number of turns – you can simply count them.

EXAMPLE EXERCISE 1

The transformer for a doorbell converts an alternating voltage of 230 V into an alternating voltage of 12 V. The primary coil has 400 turns.
Calculate the number of turns in the secondary coil.

given: primary coil: $U_p = 230$ V, $N_p = 400$; secondary coil: $U_s = 12$ V

required: $N_s = ?$

working: $\frac{U_p}{U_s} = \frac{N_p}{N_s} \rightarrow \frac{230}{12} = \frac{400}{N_s}$

$230 \times N_s = 400 \times 12 = 4800$

$N_s = \frac{4800}{230} = 21$ turns

THE IDEAL TRANSFORMER

A transformer is an energy converter: it converts electrical energy at a high voltage into electrical energy at a low voltage, or the other way round. Very little energy is lost during this process. You can often assume in calculations that there is no energy loss at all. The error caused by this can often be neglected in practice.

The power drawn by the primary coil of an **ideal transformer** (one with zero energy loss) is the same as the power supplied by the secondary coil. Expressed as a formula:

$P_p = P_s$ or $U_p \cdot I_p = U_s \cdot I_s$

where:
- P_p and P_s are the power used in the primary and secondary coils in watts (W);
- U_p and U_s are the voltages in the primary and secondary coils in volts (V);
- I_p and I_s are the currents in the primary and secondary coils in amps (A).

EXAMPLE EXERCISE 2

A welding machine (figure 5) is connected to the mains (230 V). During welding, the current through the primary coil is 16 A. The secondary coil delivers a voltage of 48 V. Calculate the current in the secondary coil. Assume that the transformer in the welding machine is ideal.

given primary coil: secondary coil:

$U_p = 230$ V $U_s = 48$ V

$I_p = 16$ A

required $I_s = ?$

working $U_p \cdot I_p = U_s \cdot I_s$

$230 \times 16 = 48 \times I_s$

$3680 = 48 \times I_s$

$I_s = \frac{3680}{48} = 77$ A

figure 5 A welder with a welding machine.

PLUS STORING ELECTRICAL ENERGY

Batteries are becoming more and more important in everyday life. You find them in electric bicycles, smartphones, electrical tools and all kinds of other gadgets. In the future, they will be playing an ever-larger role in the storage of renewable wind energy and solar energy in homes and at companies. Over recent years, the production of rechargeable lithium ion (Li-ion) batteries has therefore doubled roughly every three years.

An important property of a battery is its **capacity**. This says how long a battery can supply a given current for. You can calculate the capacity by multiplying the current by the number of hours that the battery can supply that current for. The formula for the capacity is therefore:

$C = I \cdot t$

where:
- C is the capacity in amp-hours or milliamp-hours (Ah or mAh);
- I is the current in amps or milliamps (A or mA);
- t is the time in hours (h).

A Li-ion battery (figure 6) of the type you will often find in a smartphone or a laptop has a capacity of several thousand mAh. A 3000 mAh battery can supply a current of 10 mA for 300 hours, or a current of 20 mA for 150 hours and so forth.

figure 6 Your smartphone runs on a Li-ion battery.

Practice the concepts using the *Flash cards*.

COURSE MATERIAL

1 Answer the following questions.

- **a** Why is electrical energy transported at the highest voltage possible?
- **b** Explain what is meant by an "alternating voltage with a frequency of 50 Hz".
- **c** What characteristics must a transformer have if it is to double the voltage, for example from 5 V primary to 10 V secondary?
- **d** What is meant by an 'ideal transformer'?

2 Francesca is using an adapter to recharge her mobile. The voltage between the power station and her mobile phone has been transformed up and down several times. Complete table 1. For the voltages, choose between *5 V – 230 V – 10 kV – 380 kV.*

table 1 Stepping the voltage up or down four times.

the transformer	steps the voltage		
	up or down	from	to
at the power station	up	20 kV	
at the transformer station outside the town or village			
at the substation in the town or village			
in the adapter of her mobile phone			

IN PRACTICE

3 Suzie has moved from America to the Netherlands. She wants to connect her coffee machine from the USA up to the Dutch mains. That is why she bought a "*voltage converter that converts the European voltage – a whopping 230 V – to the standard USA mains voltage*" (figure 7).
The transformer in the converter has a secondary coil with 500 turns.
Calculate the number of turns in the secondary coil.

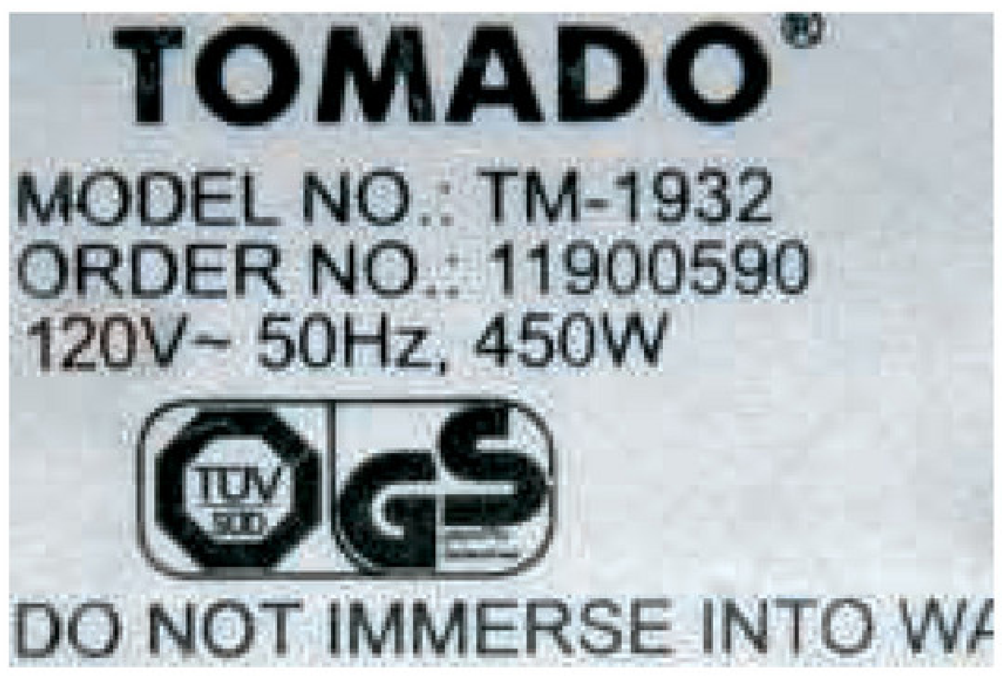


figure 7 The type plate of Suzie's coffee machine.

4 Nettie has three coils: coil A with 100 turns, coil B with 200 turns and coil C with 400 turns. She can make a simple transformer by placing two of the coils around a soft iron core.

Nettie has a source supplying 6 V. Which combination of coils lets her:

a step the voltage up to 12 V (two possibilities)?

b step the voltage up to 24 V?
The primary coil is coil *A* / *B* / *C* and the secondary coil is coil *A* / *B* / *C*.

c step the voltage down to 3 V (two possibilities)?

d step the voltage down to 1.5 V?
The primary coil is coil *A* / *B* / *C* and the secondary coil is coil *A* / *B* / *C*.

5 Barry has a voltage source that can only provide a voltage of 6.0 V. He needs a higher voltage for the experiment that he wants to carry out, so he decides to make a transformer himself. For this, he can choose between four coils with 200, 300, 400 and 600 turns respectively.

a Which combination of coils gives Barry the greatest increase in voltage?

He uses the coil with .... turns as the primary coil and the one

with .... turns as the secondary.

b Calculate how high the secondary voltage will be if he uses this combination.

c The voltage source has a switch which can be set to two positions:
= (DC voltage) and ~ (AC voltage).
Explain which type of voltage Barry must select for his transformer.

★ 6 The maximum value of the alternating voltage in the mains is 325 V and the effective value is 230 V. The following applies for the conversion: $U_{eff} = x \cdot U_{max}$

a Calculate *x*.

b An incandescent bulb uses 6.0 W when it is lit by 12 VDC. You want the bulb to run on an alternating voltage.
How big must U_{eff} be in that case?

c Calculate U_{max} for the alternating voltage.

7 Transformers are often used as 'safety transformers'. This type of transformer converts the mains voltage (230 V) down to a safe, low voltage.

a The two coils of a safety transformer have to be kept properly electrically isolated from each other using insulating materials.
Explain why this is needed.

b Write down two situations in which a safety transformer may be used.

c A safety transformer step the mains voltage down to 12 V. The primary coil has 115 turns.
Calculate the number of turns in the secondary coil.

8 An electric doorbell works on the low voltage from a bell transformer. Figure 8 shows a schematic drawing of such a doorbell transformer. The primary coil is connected to the mains (230 V). There are three connection points on the secondary side: 3 V, 5 V or 8 V.

a How high will the voltage be between the connection points P and Q: 3 V, 5 V or 8 V? Explain your answer.

b The primary coil has 800 turns.
Calculate the (total) number of turns in the secondary coil.

c A bell is connected up across terminals Q and R.
When someone rings the doorbell, a current of 0.42 A passes through the secondary circuit.
Calculate the current through the primary coil.
Assume that it is an ideal transformer.

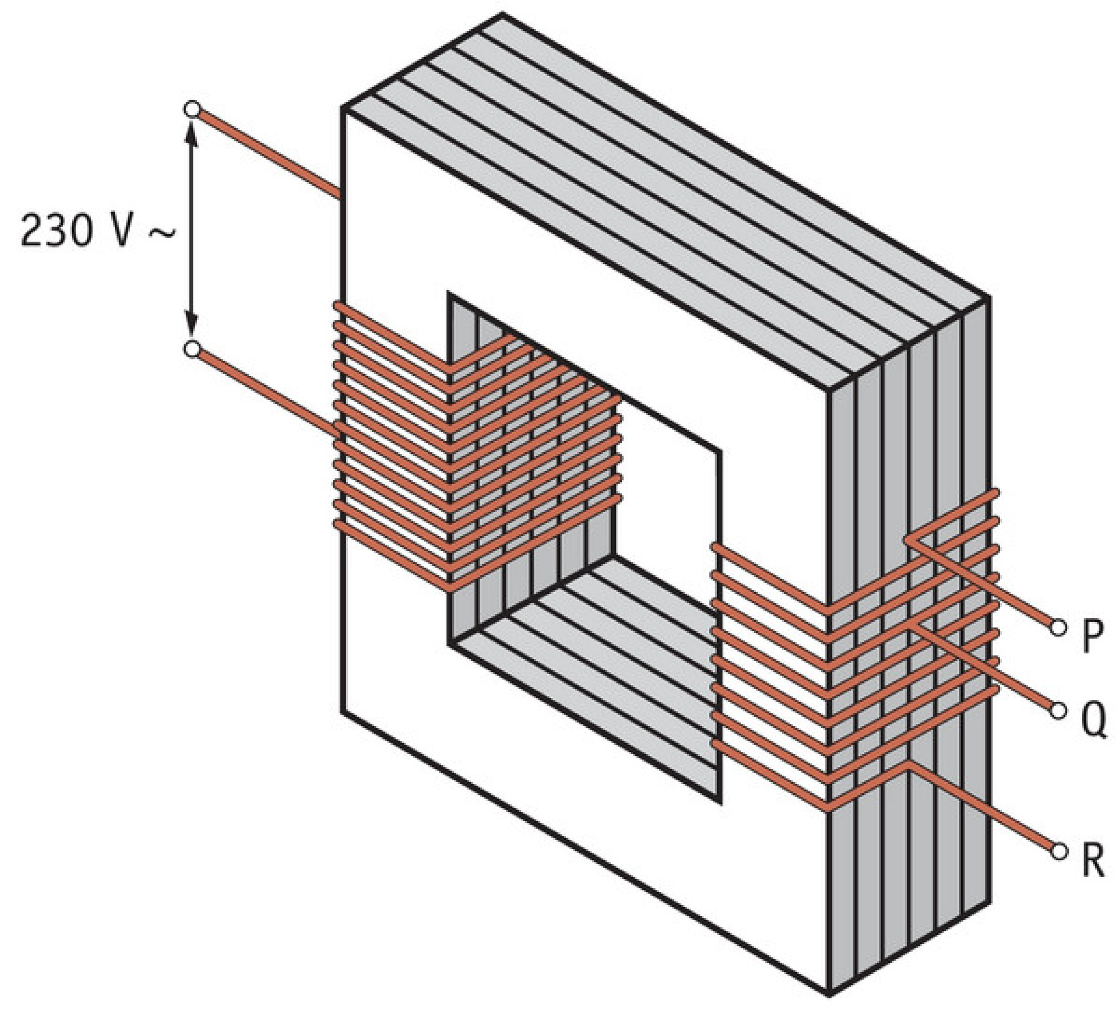


figure 8 A doorbell transformer.

★ 9 An electric toothbrush is being recharged (figure 9). There is no electrical contact between the charger and the toothbrush. Figure 10 shows you how this works. The charger uses two transformers, T_1 and T_2. The windings of the coils are just shown schematically; in reality there will be more turns.

figure 9 An electric toothbrush.

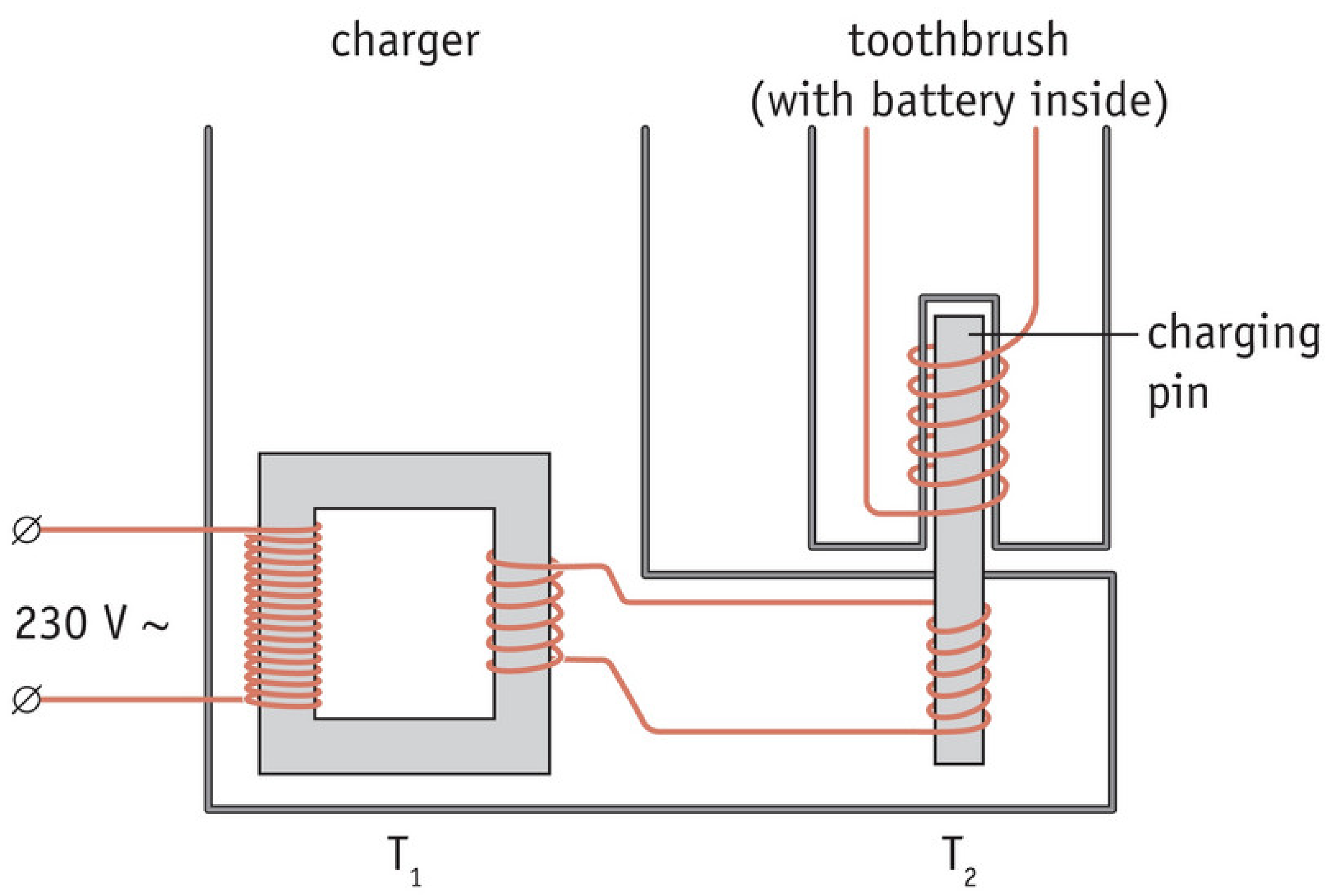


figure 10 The circuit diagram for a charger with an electric toothbrush.

a Explain step by step how electrical energy from the mains ends up in the toothbrush.

b Transformer T_1 transforms the mains voltage of 230 V down to 2.4 V. The maximum current through the secondary coil is 0.45 A.
Calculate the size of the current that then flows through the primary coil. Assume that it is an ideal transformer.

c Transformer T_2 only passes the voltage on, without making it higher or lower.
How is that possible?

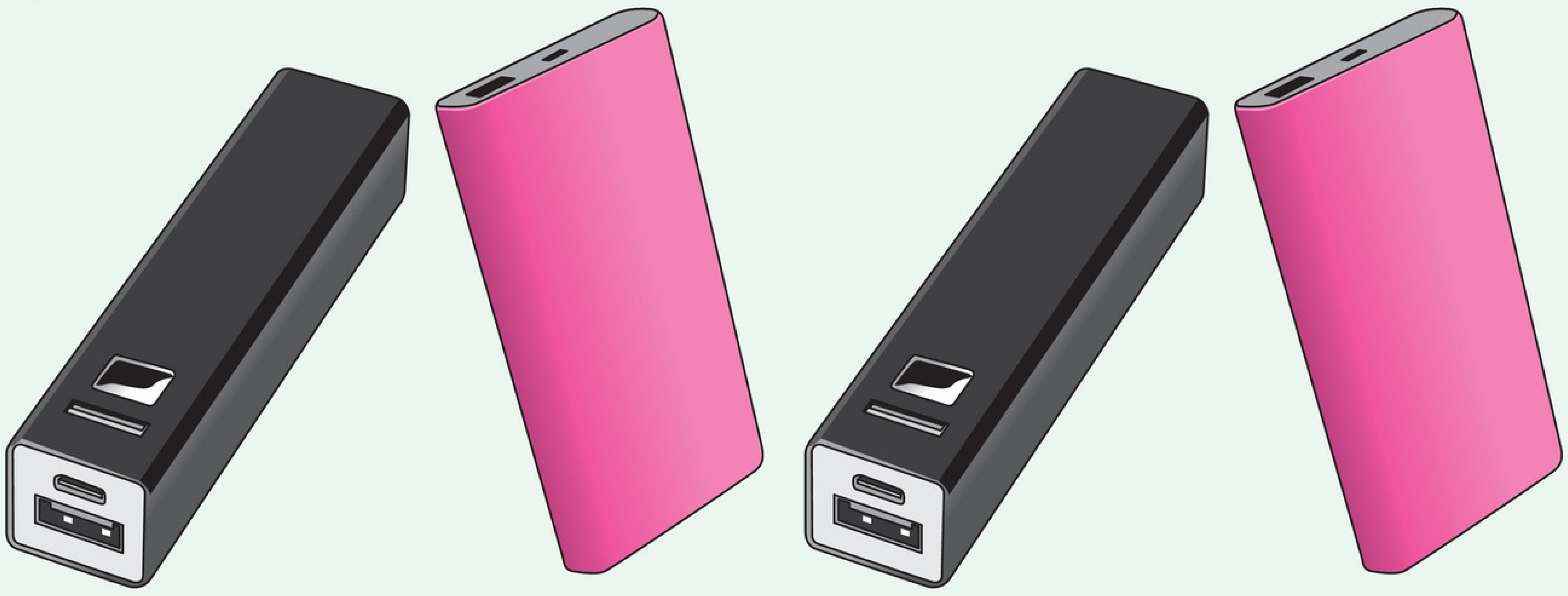
d You need a DC voltage to charge a battery. You can't use an alternating voltage for that. The alternating voltage is therefore converted into a direct voltage using a rectifier (an electronic circuit) before it goes to the battery.
Explain where the rectifier is: in the charger or in the toothbrush itself?

Test what you know with *Test yourself*.

PLUS STORING ELECTRICAL ENERGY

10 Figure 11 shows you four examples of power banks that can supply a certain current. Each power bank can supply the required current for a certain length of time.
Put the power banks in sequence from the shortest time to the longest time. Do this as far as possible by reasoning logically and explain how you determined the sequence.

figure 11 Examples of power banks that provide specific currents.



a	b	c	d
C = 2000 mAh	C = 5000 mAh	C = 2000 mAh	C = 5000 mAh
I = 50 mA	I = 100 mA	I = 100 mA	I = 50 mA

11 Wireless earphones (figure 12) contain small batteries.
The advertisement says, “The lithium-poly 60 mAh battery is a high-capacity battery providing 4.0 hours of phone or music time”.

a Calculate the current taken by these earphones when you are listening to music.

b When you recharge the earphones, it fortunately takes less than 4.0 hours. The current running through the earphones is then 35 mA.
Calculate the recharging time in minutes.

figure 12 Wireless earphones.

12 If you have solar panels on your roof, you can supply the energy generated to the electricity grid or you can use it to charge a battery. The American company Tesla has developed the Powerwall for this (figure 13). This battery stores up the solar energy that you generate during the day so that you can use it again in the evening.
Tesla’s product specifications for the Powerwall give the amount of energy that you can store in the battery: 13.5 kWh. You can use that to calculate the capacity.

a Use the two formulae for power to show that $E = U \cdot I \cdot t$

b Show that you can calculate the capacity using $C = \frac{E}{U}$

c Calculate the capacity of a Powerwall.

figure 13 A Powerwall at home.

3 Electricity in the home

LEARNING OBJECTIVES

1.3.1 You can describe how the domestic system is constructed and write down the various parts.
1.3.2 You can calculate the overall current and the total power consumption of a group.
1.3.3 You can describe the various wires in a domestic system and explain their purpose.
1.3.4 You can do calculations using the relationship between power, voltage and current.
1.3.5 You can calculate the consumption of electrical energy in a house and represent it in kWh or MJ.
PLUS 1.3.6 You can explain how a circuit breaker works.

The list of activities that you need electrical energy for is a long one. Gaming, searching for information, making coffee, listening to music, watching TV, doing the laundry – none of that is possible anymore if there's a power cut.

A DOMESTIC ELECTRICAL SYSTEM

A network of electrical wiring runs through the walls and ceilings of a home: the **domestic system**. This lets you use electrical energy anywhere in the house. Figure 1 shows you how the electricity mains enter the house near the front door. After the energy meter, the cable splits up into four to six parallel groups. To keep the diagram clear, just two groups have been drawn in figure 1.

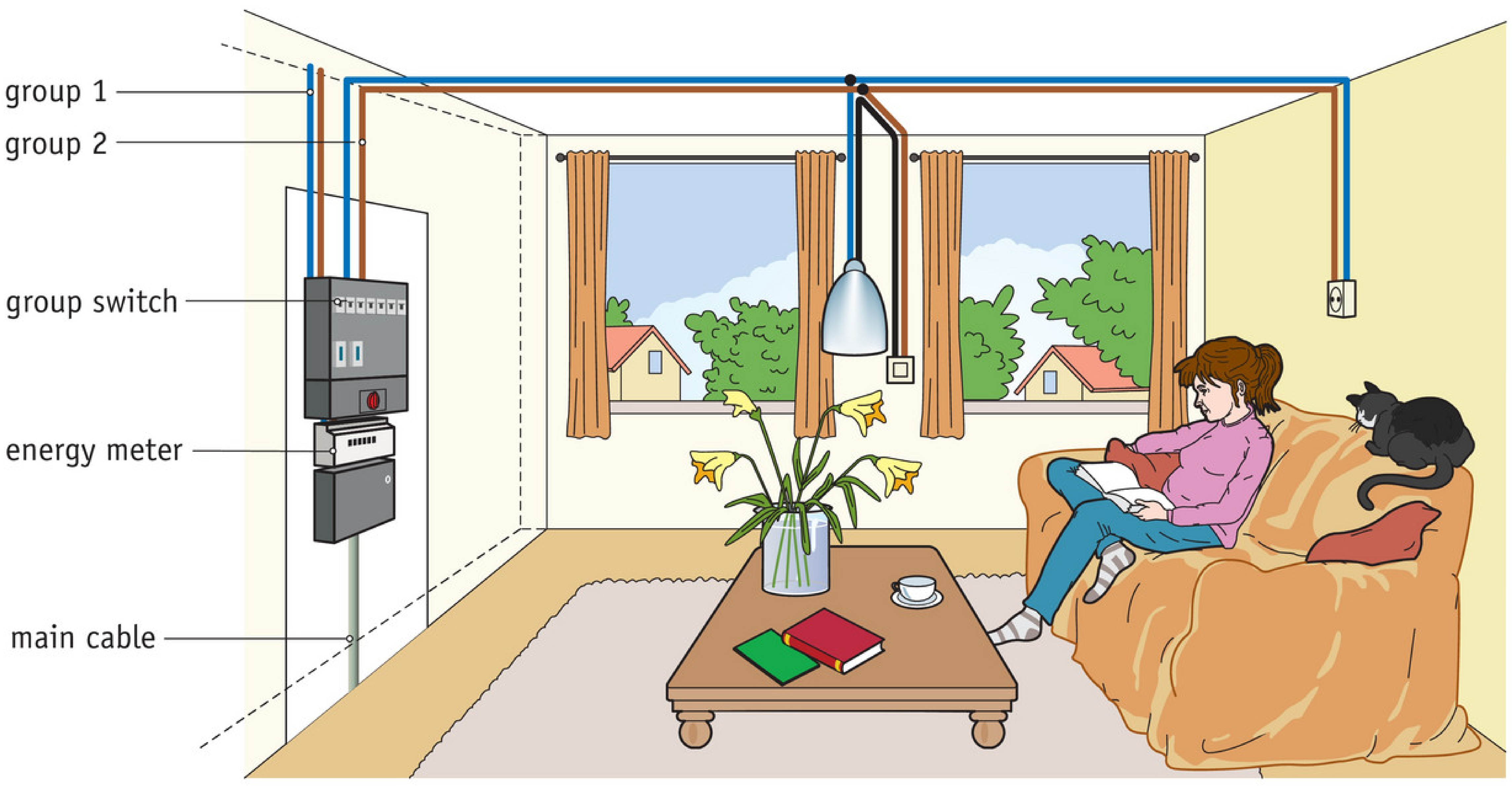


figure 1 Part of the electrical system in a home.

A group consists of various branches in parallel, each leading to one socket or one light fitting. This means that every single light fitting and socket has a voltage of 230 V. The voltage U is therefore the same everywhere in the group:

$$U = U_1 = U_2 = U_3 = ... = 230\ \text{V}$$

where:

- U is the voltage across the entire domestic system in volts (V);
- U_1, U_2 and U_3 are the voltages across the first, second and third branches in volts (V).

Each group has its own **group switch** that can be used to make sure there is no voltage at the sockets and light fittings. This makes it safe for you to perform repairs or connect up an additional socket.

If a device is on, current will run through the branch that it is connected to. The greater the power consumption of the appliance, the higher the current. If you add up all the currents in all the branches, this gives you the total current I_{tot} in the group. Expressed as a formula:

$$I_{tot} = I_1 + I_2 + I_3 + ...$$

where:
- I_{tot} is the total current for the group in amps (A);
- I_1, I_2 and I_3 are the currents through the first, second and third branches in amps (A).

As you can see, each branch is given a number of its own. I_1 runs through branch 1, I_2 runs through branch 2 and so forth (figure 2).

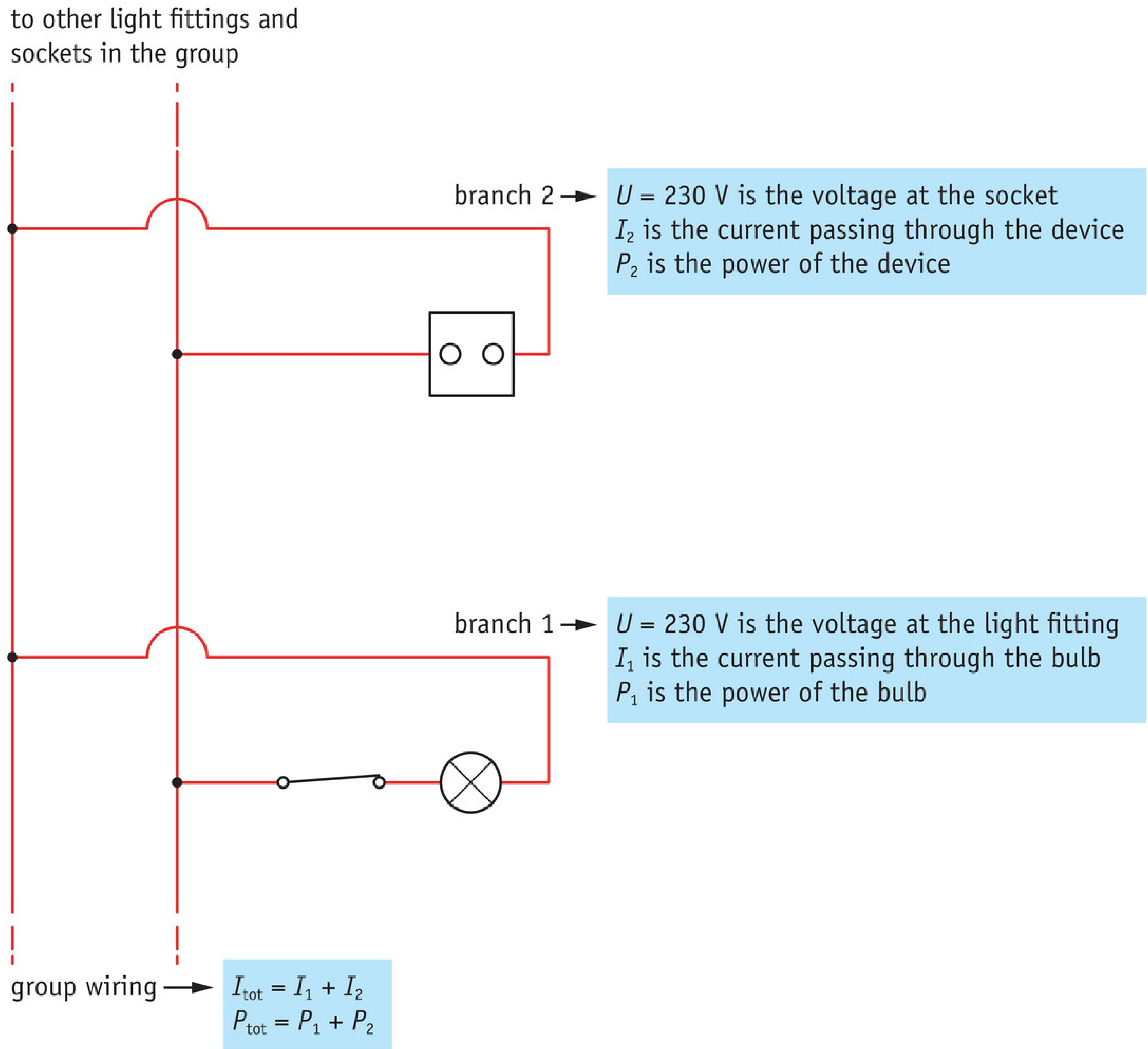


figure 2 All the light fittings and sockets in a group are connected in parallel.

CONNECTING A DEVICE

Most devices are connected up by inserting a plug into a mains socket. When you put a plug into a socket, the legs make contact with two wires from the domestic system (figure 3). These wires have a solid copper core and a PVC insulation layer around them (PVC is a kind of plastic). The brown wire is the **live wire** and the blue wire is the **neutral wire**.

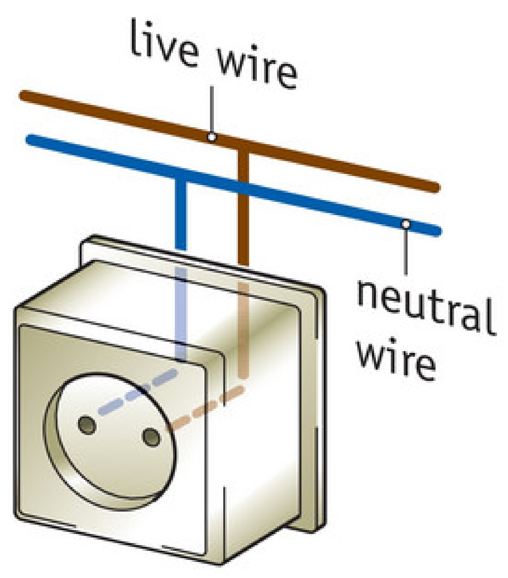


figure 3 This is how a socket is connected up.

The (brown) live wire has an alternating voltage of 230 V. You must not touch the copper core of this wire. If you do, a current will run through your body and you will get an electric shock. The (blue) neutral wire has no voltage. This wire is only there to complete the circuit that runs back to the distribution board.

If you touch the neutral wire, you should not feel anything. You do have to be careful with the blue wires too, though: someone might have swapped the brown and blue wires by accident. You should therefore always disconnect the power supply before you touch any wires.

Figure 4 shows a drawing of how a ceiling light is connected. A brown live wire goes to a switch. A black wire goes from the switch to the light: this is the **switch wire**. The switch wire will only be live when the switch is in the 'ON' position. If the switch is in the 'OFF' position, no voltage can reach the bulb. The second wire that a light is connected to is a blue neutral wire.

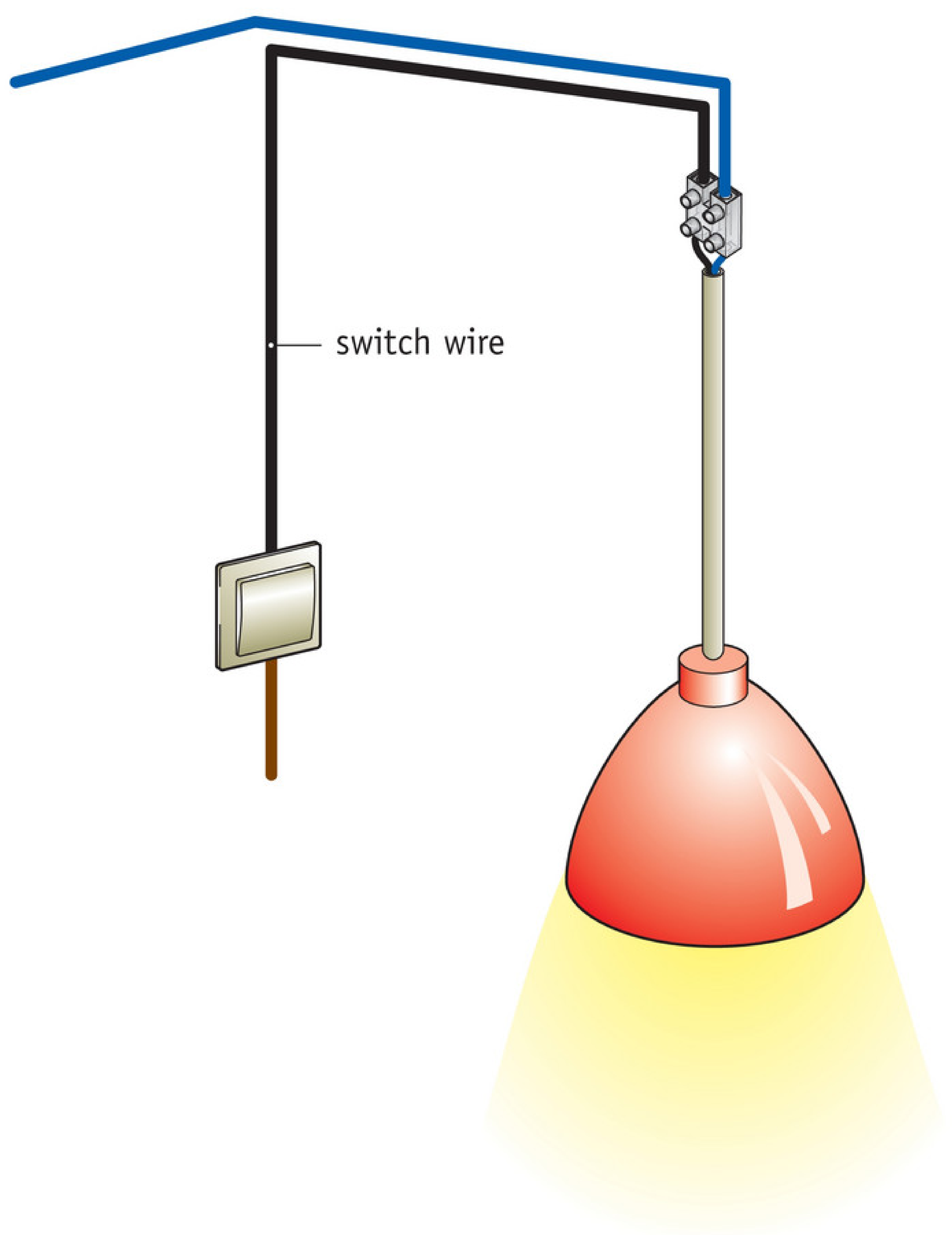


figure 4 This is how a light is connected up.

THE POWER OF A DEVICE

The power rating is stated on every electrical device, generally along with all sorts of other details. Many appliances have variable power, like a food mixer that has various positions. In that case, the maximum value is always stated. If you set the mixer in figure 5 to its highest setting, it uses 175 joules of electrical energy per second (175 W = 175 J/s). At a lower setting, the power is less.

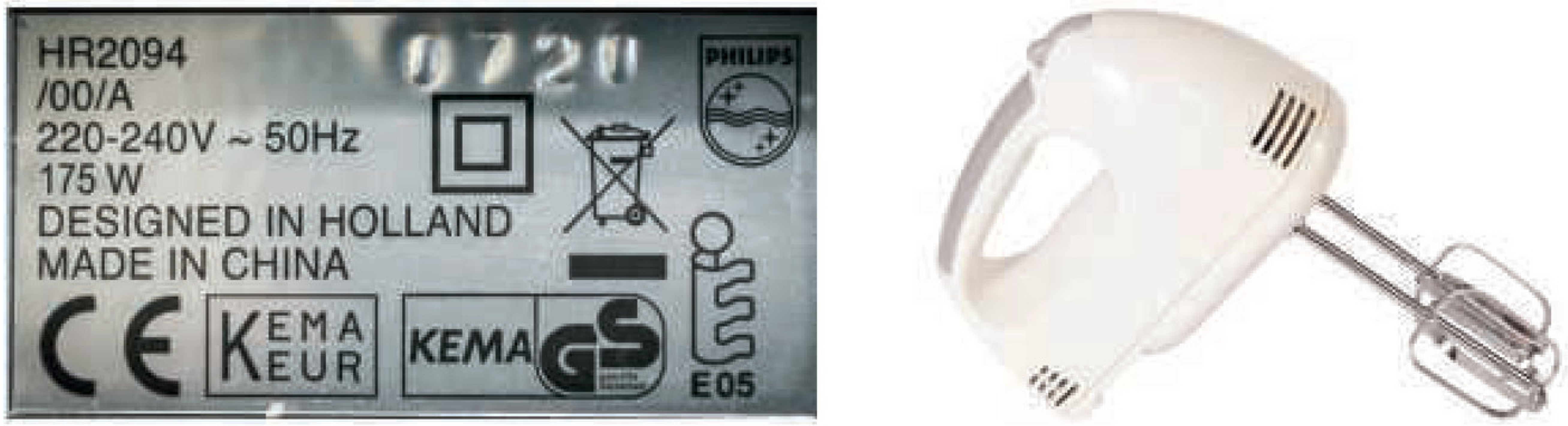


figure 5 A mixer with a maximum power of 175 W.

The power of a device depends on two factors: the voltage (across the device) and the current (through the device). You can check this by performing experiments such as the one shown in figure 6.

- In Experiment 1, a single light source is lit and the voltage across it 6.0 V. The current through the bulb is then 1.0 A.
- In Experiment 2, two bulbs are connected in series. To get both bulbs lit as brightly as the bulb in Experiment 1, the voltage has to be raised to 12 V. There is then 6.0 V across each bulb. This shows that when the voltage is doubled, the power is doubled too.
- In Experiment 3, two bulbs are connected in parallel. The voltage source has been set to 6.0 V again. The current through each bulb is then 1.0 A, with each of them lit as brightly as the bulb in Experiment 1. The current through the wire to the battery is then 2.0 A. This shows that when the total current is doubled to 2.0 A, the power is doubled too.
- In Experiment 4, two sets of two bulbs in series are connected up in parallel. The voltage source has been set to 12 V. The current through each bulb is then 1.0 A, with all the bulbs lit as brightly as the bulb in Experiment 1. The current through the wire to the battery is then 2.0 A. This shows that if you double the voltage and the current, the power goes up by a factor of four.

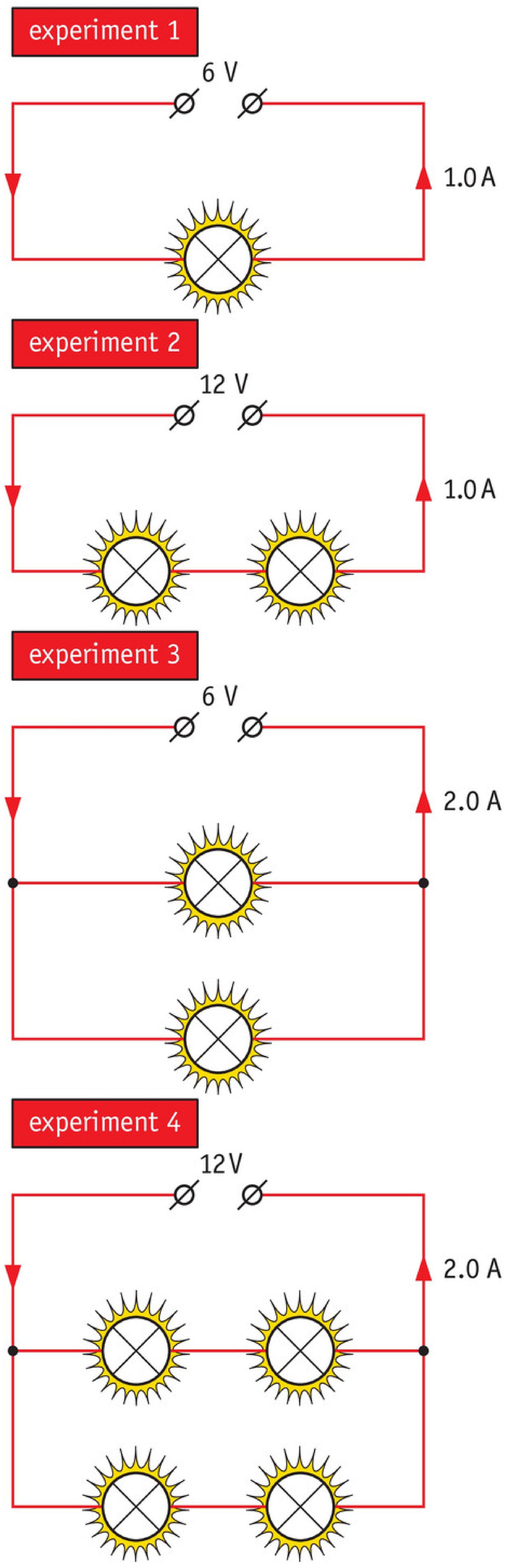


figure 6 The power depends on both the voltage and the current.

This type of experiment shows that power depends directly on both voltage and current. You can therefore calculate the electrical power using the following formula:

$$P = U \cdot I$$

where:

- P is the power in watts (W);
- U is the voltage in volts (V);
- I is the current in amps (A).

THE TOTAL POWER

The appliances that are connected to a group are almost never all on at the same time. You can calculate the total power P_{tot} (of the appliances that are on) using the formula:

$$P_{tot} = P_1 + P_2 + P_3 + ...$$

where:

- P_{tot} is the total power for the group in watts (W);
- P_1, P_2 and P_3 are the power ratings of the first, second and third devices connected, in watts (W).

If a 15 W appliance and a 40 W appliance are on at the same time, the total power being drawn is therefore 55 W. Which is logical, when you remember that 1 W is the same as 1 J/s. If one appliance consumes 15 J/s and the other 40 J/s, this gives you a total of 55 J/s or 55 W.

A second formula can be derived for P_{tot} with a few calculations:

$$\begin{aligned} P_{tot} &= P_1 + P_2 + P_3 + ... \\ &= U \cdot I_1 + U \cdot I_2 + U \cdot I_3 + ... \\ &= U \cdot (I_1 + I_2 + I_3 + ...) \\ &= U \cdot I_{tot} \end{aligned}$$

You can therefore also calculate the total power drawn by multiplying the mains voltage (230 V) by the total current:

$$P_{tot} = U \cdot I_{tot}$$

where:

- P_{tot} is the total power for the group in watts (W);
- U is the mains voltage in volts (V);
- I_{tot} is the total current for the group in amps (A).

EXAMPLE EXERCISE 1

The following appliances are connected to one group of a domestic supply:

- an 800 W microwave
- a 2000 W kettle
- a 150 W extractor fan
- six 3.0 W LEDs

Calculate the total current for the group.

given
$P_1 = 800$ W
$P_2 = 2000$ W
$P_3 = 150$ W
$P_4 = 6 \times 3.0 = 18$ W
$U = 230$ V

required
$I_{tot} = ?$

working
$P_{tot} = P_1 + P_2 + P_3 + P_4$
$P_{tot} = 800 + 2000 + 150 + 18 = 2968$ W
$I_{tot} = \dfrac{P_{tot}}{U} = \dfrac{2968}{230} = 13$ A

MEASURING ENERGY IN kWh

EXP. 2+3

Although the joule is the official unit of energy, another unit is used on the electricity bill: the kilowatt-hour (kWh). The same unit is used by the meter that measures the consumption of electrical energy in your home. This is why this type of meter is known as a **kWh meter** or **energy meter** (or commonly just an 'electricity meter'). In the formula $E = P \cdot t$, you can give the power P in kW and the time t in hours; this then gives you the energy consumption E in kilowatt-hours.

The kWh is an old unit that should really be replaced by joules. In principle, energy consumption could be measured in MJ just as easily as in kWh. Even so, the energy companies are still sticking to kWh because all their systems are set to use that unit. Even now that all the energy meters in the Netherlands are gradually being replaced by 'smart meters', the kWh is still being used (figure 7).

As both units are used at the moment, you sometimes have to convert a quantity of energy from kWh into J or the other way round. 1 kWh equal 3.6 MJ. Work it out for yourself: if a device using 1 kW of power (= 1000 W) runs for exactly 1 hour (= 3600 s), it consumes:

$E = P \cdot t$	$E = P \cdot t$
$E = 1\ \text{kW} \times 1\ \text{h}$	$E = 1000\ \text{W} \times 3600\ \text{s}$
$E = 1\ \text{kWh}$	$E = 3.6 \cdot 10^6\ \text{J} = 3.6\ \text{MJ}$

figure 7 Even 'smart' energy meters still use kWh.

EXAMPLE EXERCISE 2

Hughie estimates that his desk lamp (6.0 W) is on for approximately 60 hours in a month (figure 8).

Calculate:

- how much electrical energy the lamp consumes in 60 hours;
- how much that electrical energy costs. 1 kWh costs € 0.23.

given $P = 6\ \text{W} = 0.006\ \text{kW}$
$t = 60\ \text{h}$

required $E = ?$

working $E = P \cdot t = 0.006 \times 60 = 0.36\ \text{kWh}$
price: $0.36 \times 0.23 =$ € 0.08

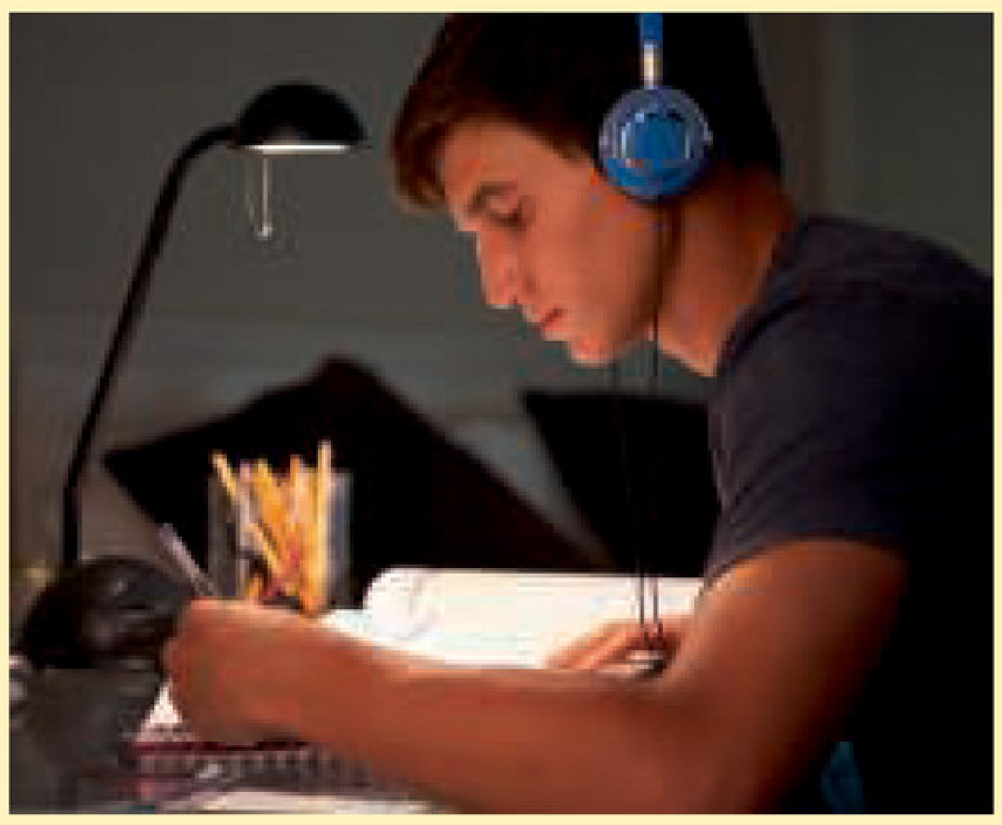


figure 8 Hughie's desk lamp.

PLUS CIRCUIT BREAKERS

Each group in your home has a circuit breaker as well as a group switch (figure 9). It is dangerous if the current in a group gets too high because too much heat will then be generated in the wires. The circuit breaker then makes sure that the voltage is disconnected from the group automatically. Most houses have 16 A circuit breakers.

Figure 10 is a schematic drawing showing the interior of a circuit breaker. The current to the group is switched off automatically if the lever mechanism pushes against the switch. It then pops open, breaking the circuit.

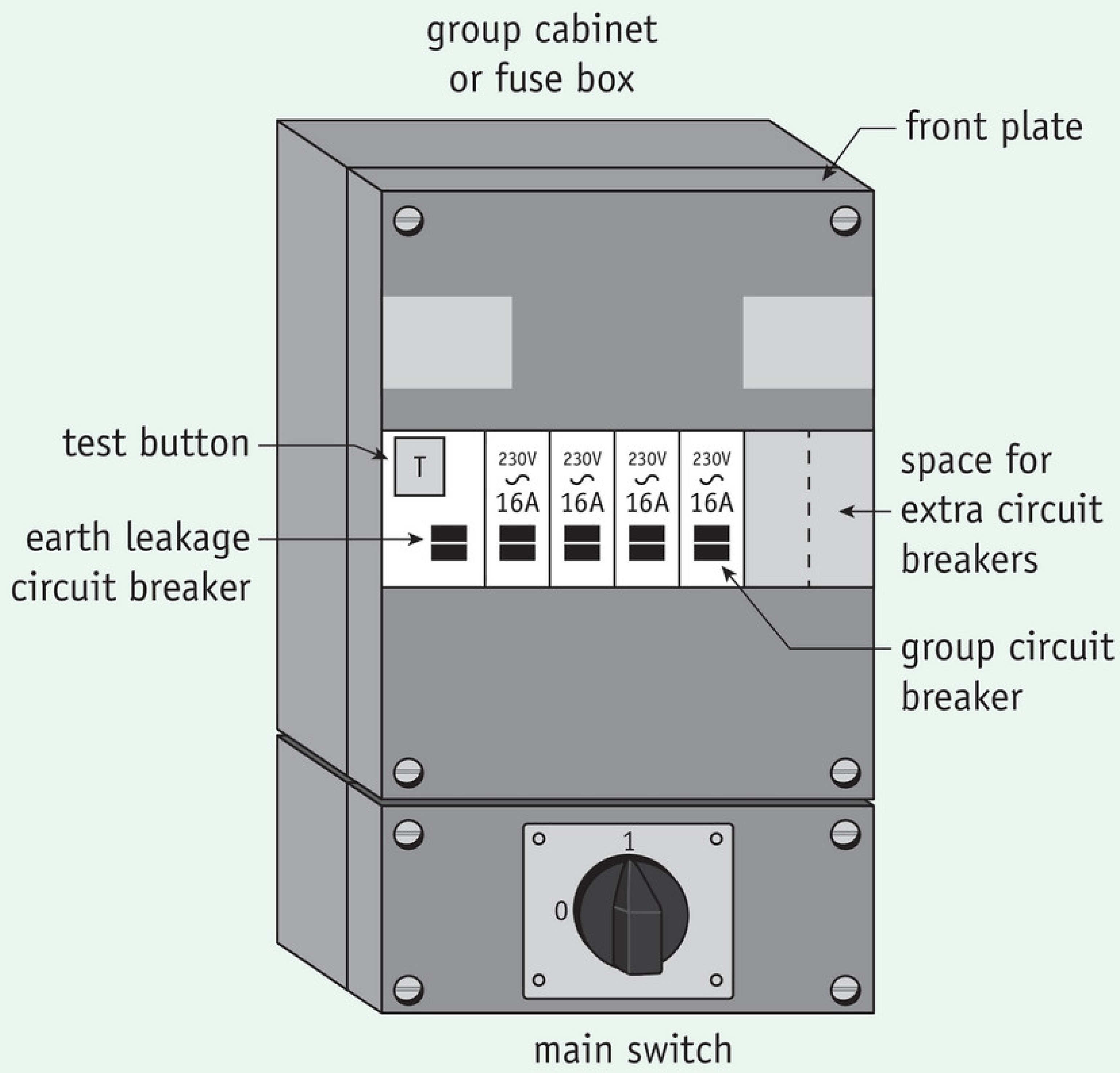


figure 9 Circuit breakers for each group in the home.

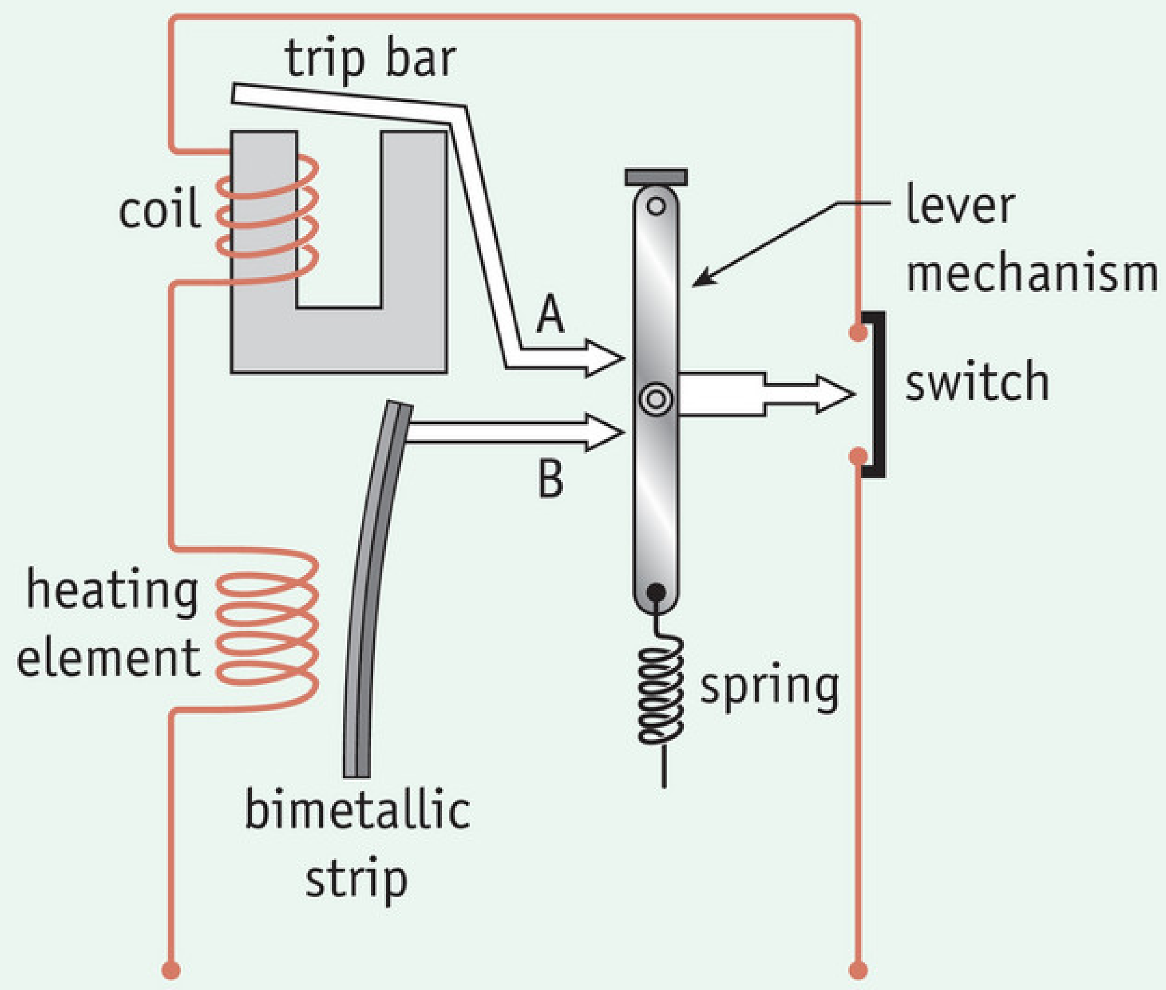


figure 10 Schematic drawing of the interior of a circuit breaker.

There are two ways that the lever mechanism can be activated:
1 At the top left in figure 10, you can see a coil with a U-shaped soft iron core. When a current passes through the coil, it acts as an electromagnet. If the current is very large, the trip bar is pulled downwards so that arrow A pushes against the lever mechanism.
2 The heating element at the bottom left of the diagram heats a bimetallic strip. This is made of two strips of different metals, attached firmly together. At room temperature, the strips are the same length, but one of the metals expands more when heated than the other, so the bimetallic strip will then bend (figure 11). When the current is too high and heat is produced, arrow B will push against the lever mechanism.

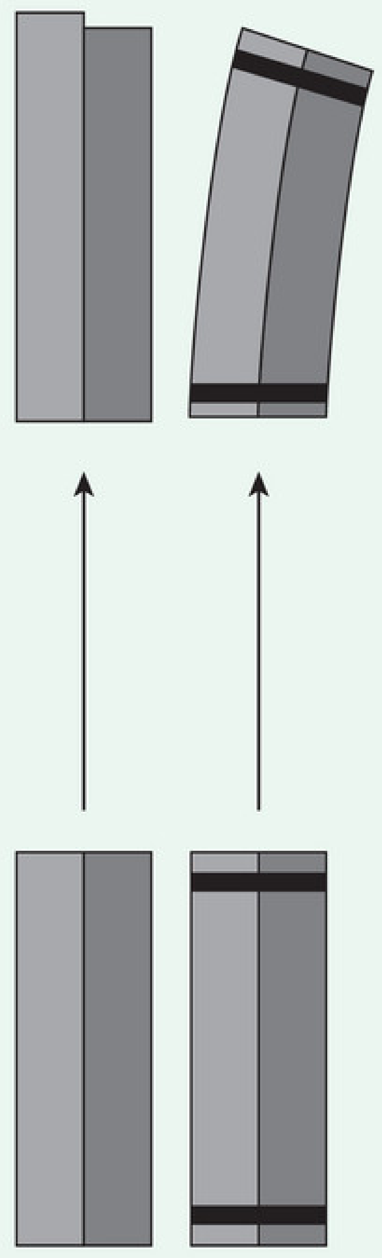


figure 11 Two strips of different metals that are not attached together (top) and two strips that are (bottom). The metals are shown at room temperature on the left and at a higher temperature on the right.

Practice the concepts using the *Flash cards*.

COURSE MATERIAL

1 Answer the following questions.
- **a** Which two formulas can you use to calculate the total current in a group?
- **b** What are the differences between a live wire, a neutral wire and a switch wire?
- **c** How is it possible that a device that does not require much power sometimes uses a surprisingly large amount of energy?
- **d** Which two factors determine the power of an electrical appliance?
- **e** What instrument measures how much electrical energy is being consumed in the home?

2 Table 1 gives a list of the variables and units that are used in this chapter. The official scientific units (also known as the SI units) are stated.
- **a** Write down the missing words and symbols (letters) in the table.

table 1 Variables and units.

variable	symbol	unit	symbol
			A
	U		
power			
		second	
			J

- **b** Which two units are used a lot in this chapter but are not shown in table 1?
- **c** Why do you also need to learn to work using these units, despite them not being the official scientific units?

IN PRACTICE

3 A hanging lamp is usually connected to a light fitting in the ceiling. A DIY book explains what you have to do when fitting it (figure 12).

a The black wire that is mentioned in the text is a ....

b The other connecting wire is called the .... and its colour is ....

c You can make the black wire 'dead' by turning the light switch off. Explain why this is not such a safe method.

d What is a safer way to make sure that a light fitting or socket will be 'dead' (have no voltage)?

e Why is it sensible to lock the meter cabinet after that and to take the key with you?

Safety first

- Before you start connecting the flex, make sure that the wires in the ceiling are not live. You can check this using a properly working voltage detector.
- If the black wire from the ceiling is still live, you can disconnect the voltage by switching off the appropriate light switch. However, it is always safer to switch off the group in question in the meter cabinet, lock the door of the meter cabinet, and keep the key with you while you are working.

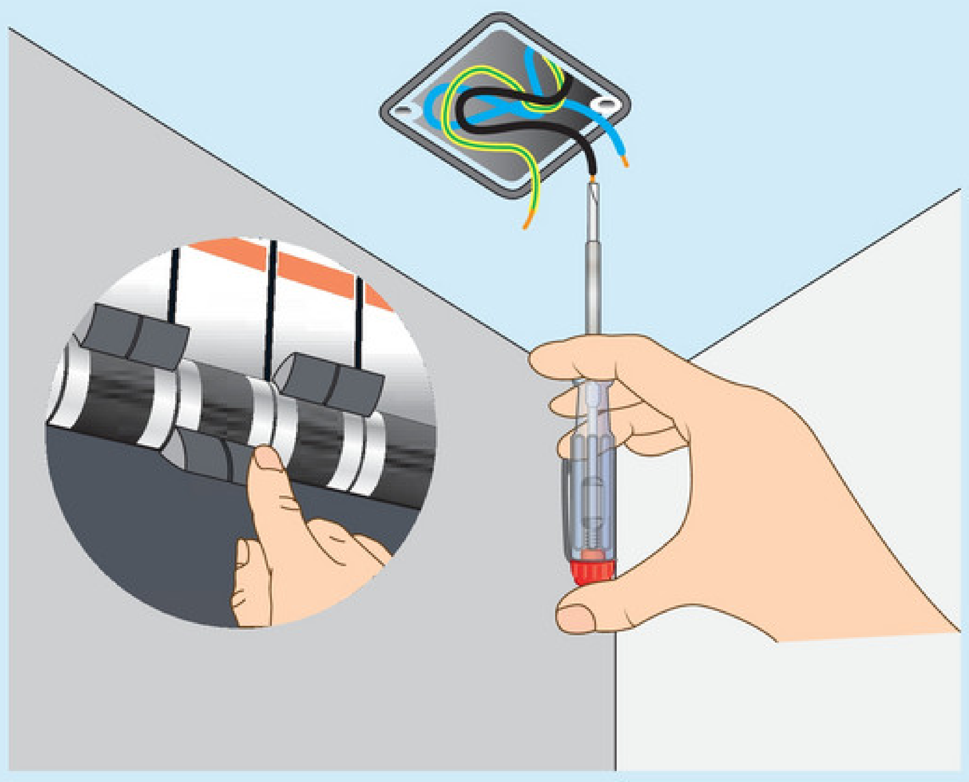


figure 12 An excerpt from a DIY book.

4 Calculate the power of the appliances below. See the skills section on *Rounding off results*.

a Tony's calculator works on a 1.5 V battery; its current is 0.080 mA.

b Bridget's vacuum cleaner is connected to the mains (230 V). The current is 7.8 A.

c Connie turns on the starter motor of her car; the battery delivers 8.1 V at a current of 160 A.

5 The following appliances are connected to one group of a domestic supply:

- a non-fat fryer with a rating of 2100 W
- a LED lamp with a rating of 9.0 W and another rated at 4.0 W
- an extractor hood of 250 W
- an LCD TV with a rating of 90 W

a Calculate the total power.

b Calculate the total current for the group.

★ 6 Munir has made a circuit using a battery, three different bulbs and an ammeter (figure 13). The battery delivers a voltage of 6.0 V. The writing on bulb 1 says that it is 6 V/1.5 W. The writing on bulb 3 says that it is 6 V/2.1 W. The ammeter shows that the current is 0.80 A.
Calculate the power rating of bulb 2. Show all your calculation steps.

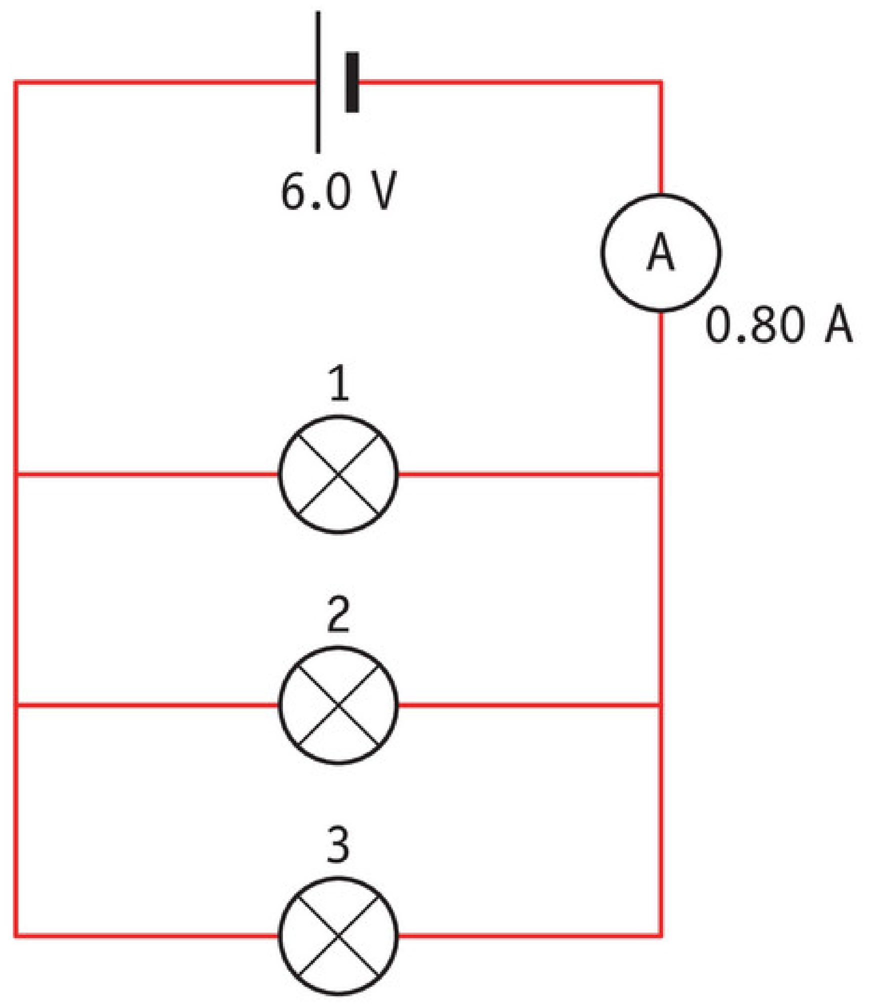
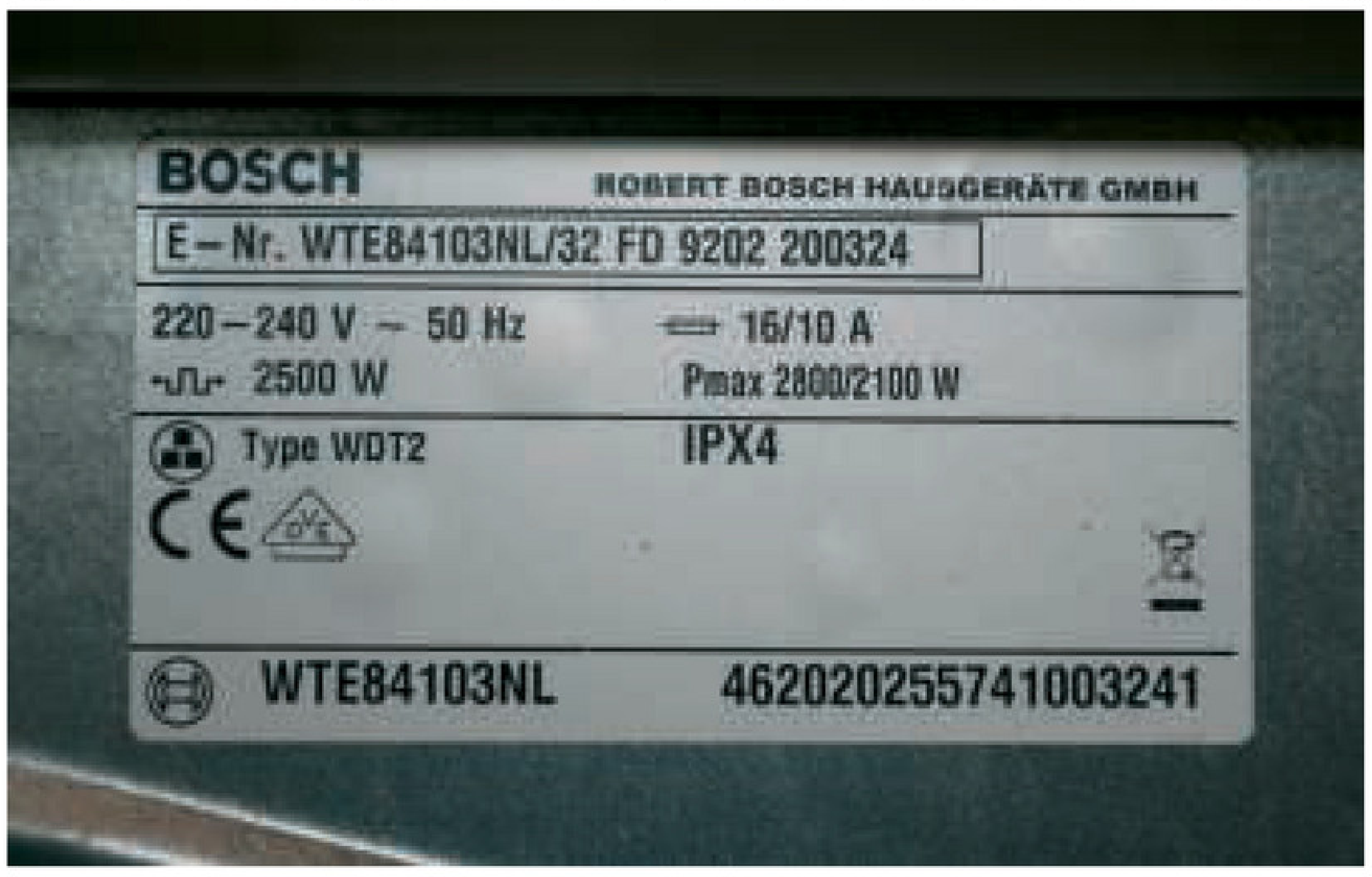


figure 13 Munir's circuit.

7 Figure 14 shows the rating plates of a dryer and an electric toothbrush.

figure 14 Rating plates of a dryer (a) and an electric toothbrush (b).



a

b

a It takes 1.6 hours for the dryer to make sure that the clothes are dry.
Calculate how much electrical energy is required for this (in joules and in kilowatt-hours).

b Joey brushes his teeth for 2.0 minutes in the morning. When he puts the toothbrush back on the charger, it needs 6.0 minutes to fully recharge the toothbrush.
Calculate how much electrical energy is required for this (in joules and in kilowatt-hours).

If you need more practice in *Calculating electrical power*, go to the *Skills Trainer*.

c If you buy an electrical appliance, it may be important to consider its power rating.
Which appliance do you definitely have to take the rating into account for: a dryer or an electric toothbrush? Explain your answer, using a calculation.

In the following exercises, assume that 1 kWh of electrical energy costs € 0.23 (the price in 2019).

★ 8

Samia uses her washing machine twice a week. She does the wash at 60 °C. She wants to save on her energy costs and wonders how much she will save if she did her laundry at 30 °C from now on. In figure 15, the energy consumption of the wash cycle has been plotted against the temperature of the washing water.
Calculate how much money Samia can save annually (rounded off to the nearest whole euro).

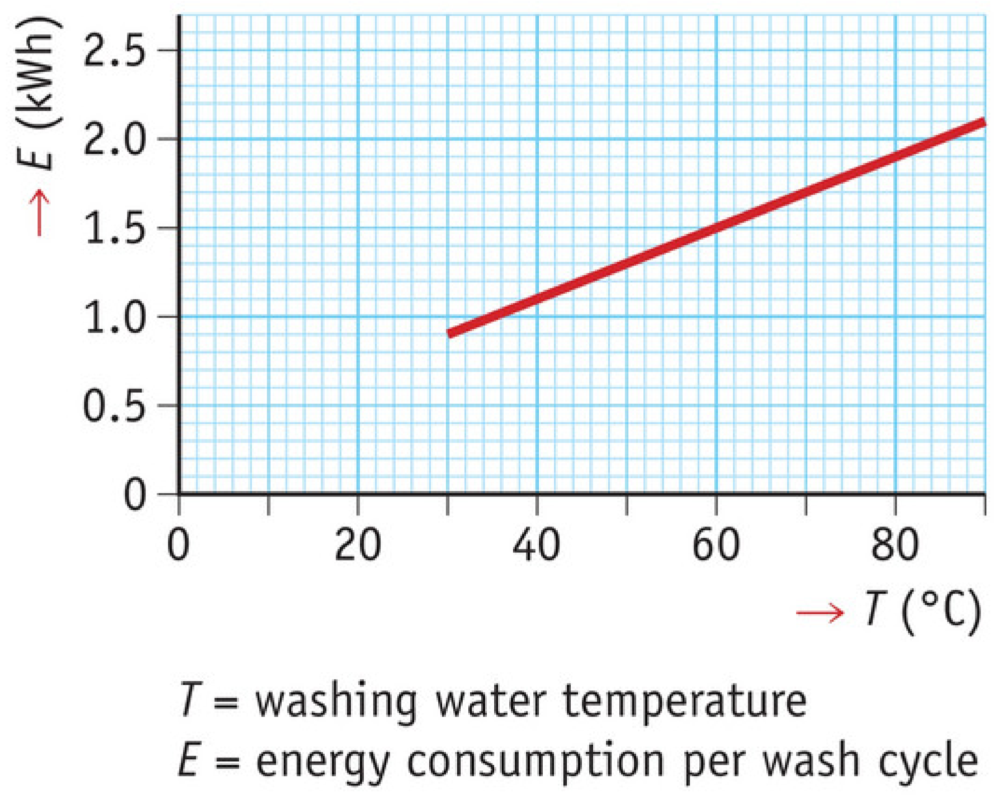


figure 15 The energy consumption per washing cycle.

★ 9

When Jacqueline is not watching it, her TV is always on standby. She is wondering if this means that her energy bill is a lot higher. So she measures the power consumed by her TV when it is on standby. That turns out to be 4.0 W. When the TV is on, the power is 260 W.

a Imagine that the TV is left on standby for a whole year.
Calculate how much electrical energy the TV uses each year.

b Calculate how much Jacqueline has to pay for this electrical energy.

c Jacqueline watches TV for 1.5 hours a day on average.
Calculate how much electrical energy the TV uses in total.

d What percentage of this total is the stand-by energy consumption?

Test what you know with *Test yourself*.

PLUS CIRCUIT BREAKERS

10 The trip bar at the top left of figure 10 is pulled downwards when the current is very large.

a What can you say about the material that the trip bar is made of?

b The bimetallic strip at the bottom left in figure 10 bends to the right when the current for the group gets too high.
Explain whether it is the left or the right side of the bimetallic strip in figure 10 that expands more when the current is too high.

11 A 16-amp circuit breaker is not enough for devices that use a lot of electrical energy, such as a Jacuzzi. You can then install a separate group with a 25-amp circuit breaker.
Using figure 10, explain three ways that it would be possible to modify a 16-amp circuit breaker so that the current is only switched off at 25 A. Think of at least three possibilities.

12 Figure 16 shows a graph in which you can see the time that a circuit breaker takes to turn off as a function of the current.
The scales for both the *x*-axis and the *y*-axis are non-linear. At the bottom of the graph, there is a square for just 0.01 s but the top square is for 4000 s.

a Explain why the person drawing the graph chose a scale like this.

b Pat and her parents are having a large party in their home. They have decided to serve some deep-fried snacks but they need to connect up two deep fat fryers to do that. Both fryers have a power rating of 2.75 kW. They are connected up to a single group. Assuming that the snacks take 10 minutes to cook through and the fryers' heating elements are on all the time, use figure 16 to help work out whether the snacks will be cooked right through.

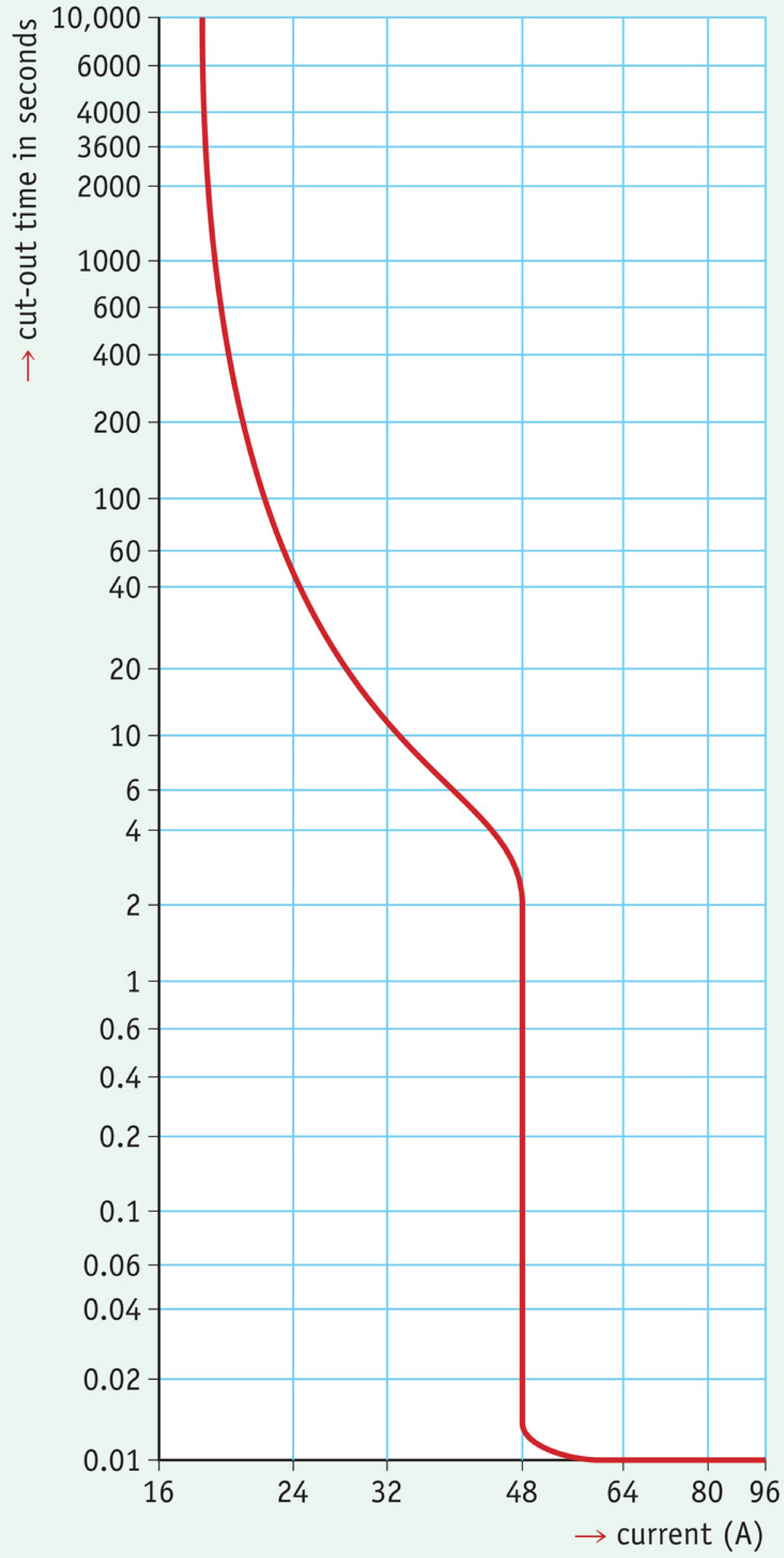


figure 16 The cut-off time of a 16-amp circuit breaker depends on the current.

4 Electricity and safety

LEARNING OBJECTIVES

1.4.1 You can explain the dangers of using electricity.
1.4.2 You can explain what circuit breakers (group fuses) do.
1.4.3 You can explain what 'single insulation' and 'double insulation' mean.
1.4.4 You can explain what earth leakage circuit breakers and earth connections do.
1.4.5 You can write down and identify the safety features, both in real life and in photos.
PLUS 1.4.6 You can explain the phenomenon of induced voltage.

Safety comes first when designing a domestic system. The wires are well-protected against damage and they are thoroughly insulated. They also have special safety features such as fuses and earth connections. The chance of accidents with electricity is therefore very small as long as you are careful.

DANGERS OF ELECTRICITY

If wires have to carry too much current, they can become so hot that they cause fires. This can be the result of overloading or short circuits.

- **Overloading** means that there are too many devices running on a group at the same time. As a result, that group is drawing too much power. This means that the current goes above the safe limit (usually 16 A). If that keeps happening, it is a good idea to install an extra group.
- **Short-circuiting** happens when the insulation of an appliance or wire fails. This lets the current take a different path with much less resistance. Figure 1 gives an example. The copper wires inside the plug are in contact with each other. If you put this plug in the socket, the current can go straight from the live wire to the neutral wire. The current will then suddenly be huge.

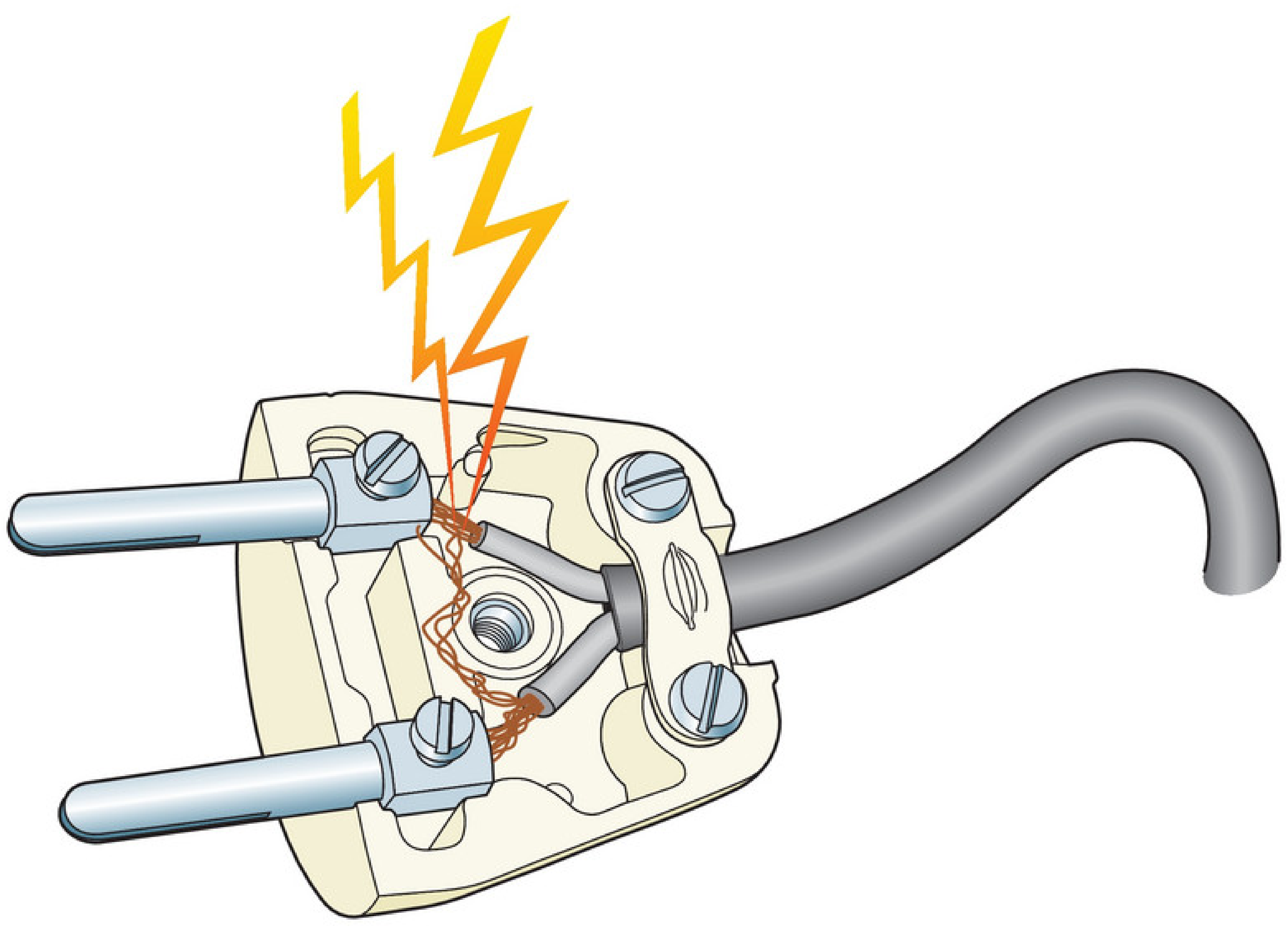


figure 1 If you use this plug, it will cause a short circuit.

There is a second danger as well as fire. You might notice this if you touch the electric fencing around a field (figure 2). An electric current runs through your body and it is not a pleasant sensation. The current makes your muscles suddenly contract powerfully and you get a shock. With an electric fence, that is only unpleasant. But a shock from the mains can be dangerous.

figure 2 If you touch an electric fence, your muscles will suddenly contract strongly.

If the current passing through your body is not too high, you will still be able to control your muscles. You can let go of the live object immediately. But if the current is higher and does not stop immediately, your muscles cannot relax. In that case, you can't let go of the live object anymore. Table 1 shows you what the consequences can be.

table 1 The effect of current on your body.

current	symptom
0.5 – 5 mA	tingling sensation, shock reaction
5 – 20 mA	painful cramps in the muscles
20 – 50 mA	muscular contractions including the chest muscles; breathing problems
50 – 200 mA	heart problems; cardiac fibrillation
200 mA – 1 A	major damage to tissues, muscles and nerves
more than 1 A	life-threatening; burns; coagulation of proteins

Source: extranet.infopuntveiligheid.nl

The size of the current depends on the voltage and the resistance of your body. Your body conducts currents quite well: the **electrical resistance of your body** is therefore not very high. The highest resistance to the current is at the points where it enters and leaves the body. This is called the **contact resistance**.

If your skin is dry, contact resistance will be quite high. But if your skin gets wet, this will lower the contact resistance a lot. Boots with rubber soles have a high contact resistance and so they reduce the current. But it is always better not to touch a conductor that is at a voltage of more than 30 V.

FUSES

The meter cabinet has various safety features (figure 3). Each group has its own **group fuse**. Those fuses make sure that the current in the group does not get too high. The maximum current a group can take safely is normally 16 A. If the current in a group exceeds 16 A, the group fuse will turn off the power. This prevents the wires from becoming so hot that they could cause a fire.

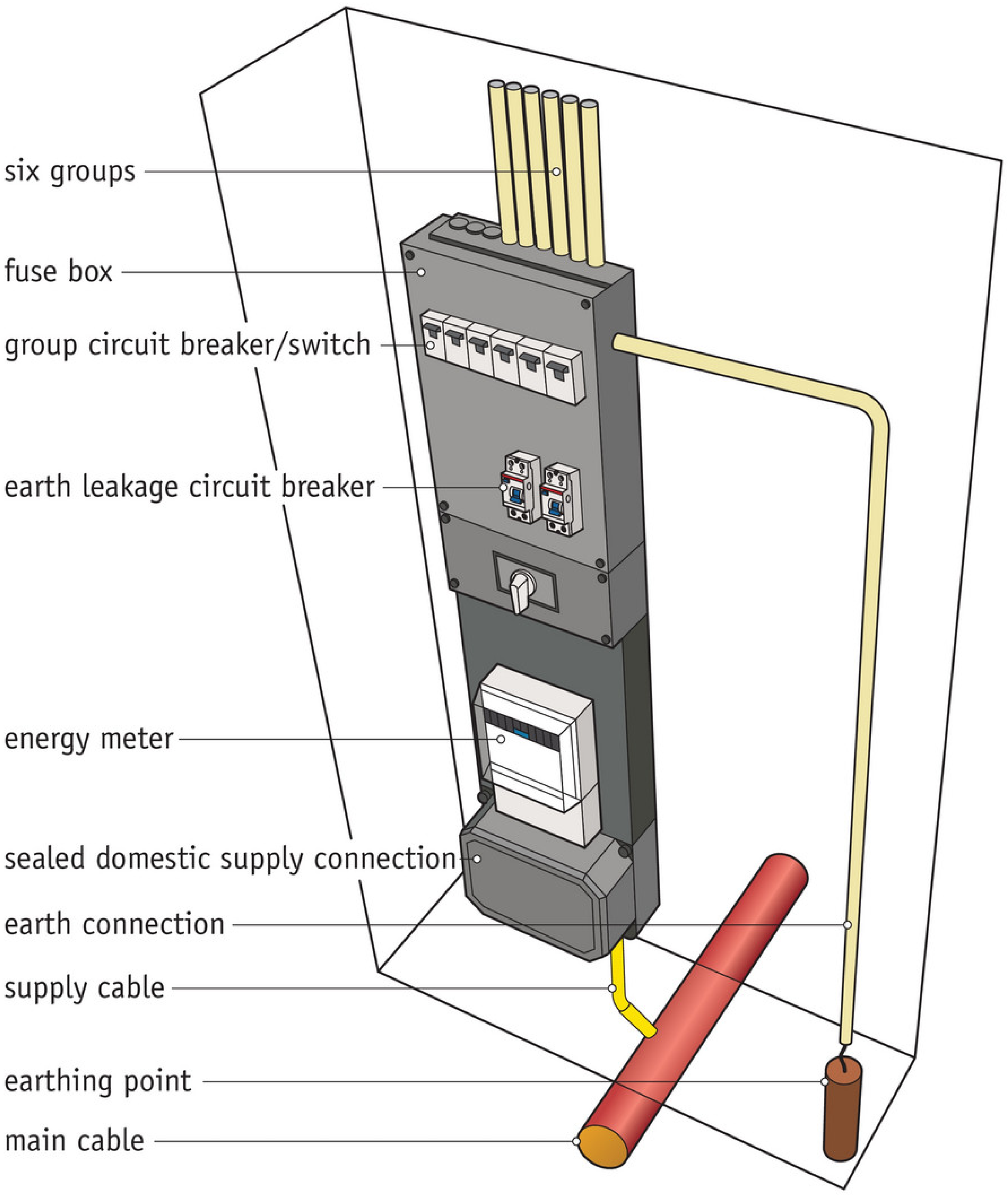


figure 3 This is what you will find in the meter cabinet.

Modern domestic systems use electronic fuses called **circuit breakers**. These circuit breakers have a small lever that 'flips' when the power is turned off (figure 4). This lets you see which group the fault is in straight away. Once the fault has been fixed, you can switch on power again by flipping the lever up.

figure 4 A row of circuit breakers.

SINGLE AND DOUBLE INSULATION

The wires in a household electrical system have a solid copper wire as their core. The thickness of this wire has been chosen so that currents of up to 16 A can run through it easily, without significant heat production. An insulation layer of coloured PVC makes sure that you will not get a shock when you touch the wire. The insulation is also needed to prevent short circuits between the wires.

The wiring goes through insulating PVC tubes or is embedded in a thick cable with grey insulation. The wires therefore have **double insulation**. Appliances can be doubly insulated too. The parts that the current runs through are insulated as normal. In addition, the outside of the appliance is made of a non-conducting plastic. You can recognize an appliance that is double-insulated by the symbol shown in figure 5.

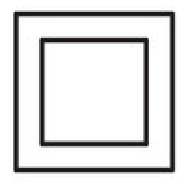


figure 5 The symbol for double insulation.

EARTH LEAKAGE CIRCUIT BREAKERS

As well as fuses, the meter cabinet also has one or more **earth leakage circuit breakers** (figure 6). An earth leakage circuit breaker (ELCB) compares the current in the live wire (brown) against the current in the neutral wire (blue). If the two currents are equal – as they normally should be – the ELCB will let the current pass.

Figure 7 shows a drawing of a situation in which the two currents are different. The metal outside of the appliance has become live because of a defect in the insulation. As a result, current 'leaks' when someone touches the appliance. The current in the neutral wire is now less than the current in the live wire.

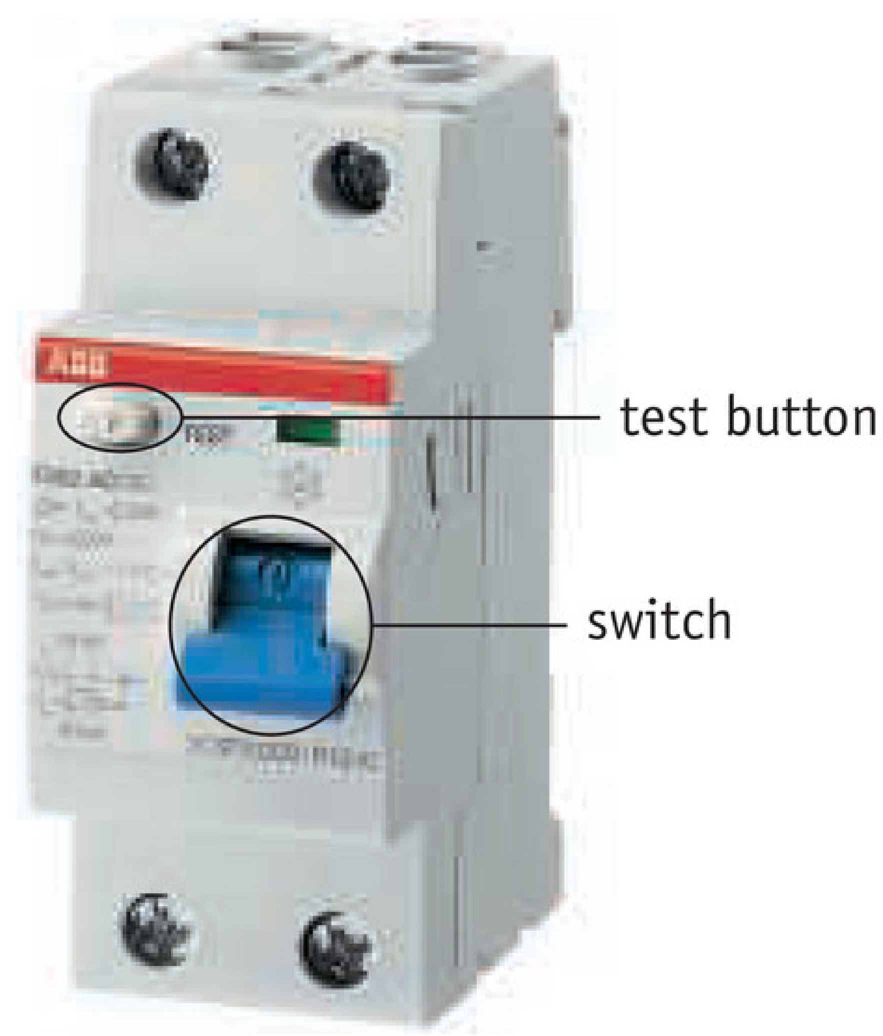


figure 6 Use the test button to check whether the earth leakage circuit breaker is working properly.

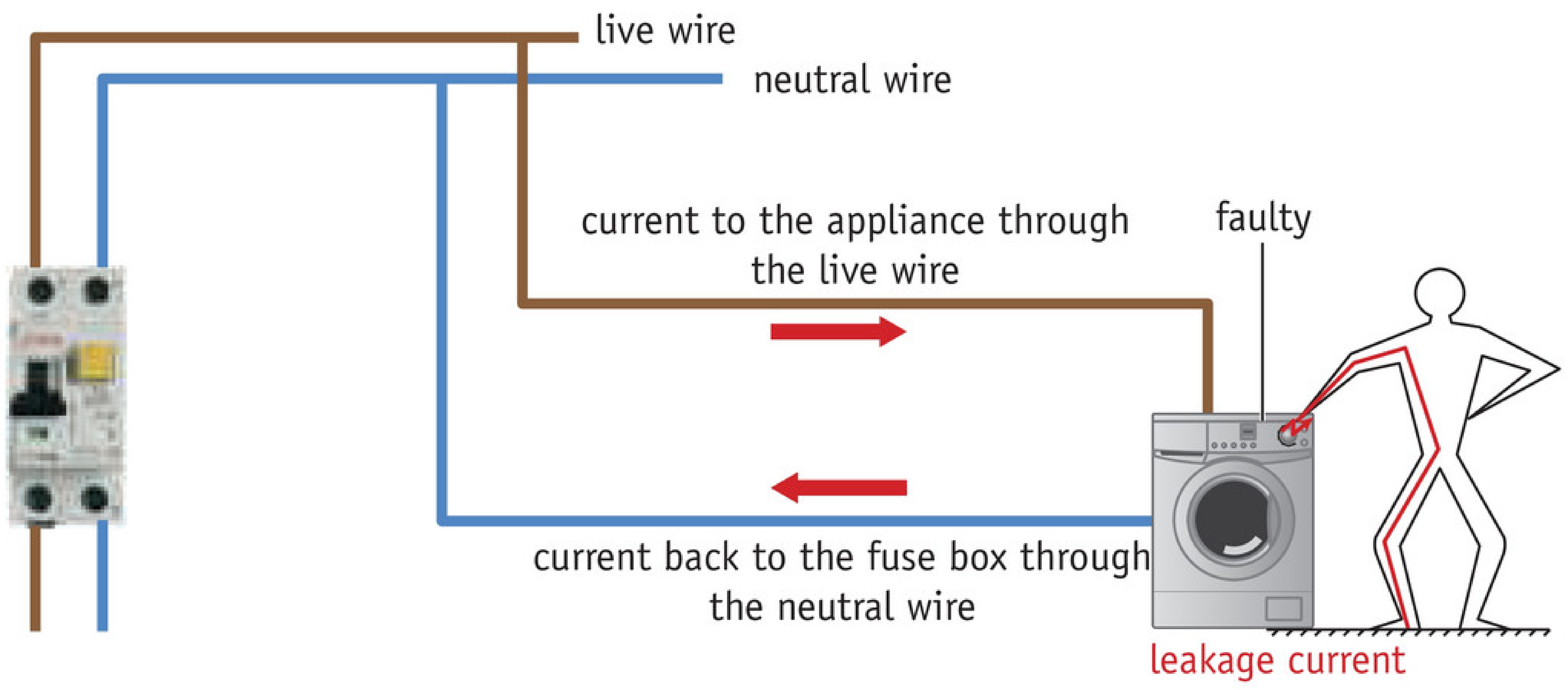


figure 7 The ELCB turns off power when there is a leakage current.

If the difference in current exceeds 30 mA, the earth leakage circuit breaker will turn off the power. The current cannot then leak through your body (or by any other route). If you touch the appliance, you will get a shock, but that is all: the power is turned off almost at the same moment.

EARTHING

You don't want the leakage current to be passing through anyone's body. That is why appliances are often earthed. A yellow-and-green **earth wire** connects the outer casing of the appliance via the flex to the earth pin – the outer edge of a standard European socket (figure 8). The earth wire then goes from the socket to the earth rail in the meter cabinet. That earth connection is in turn connected to a metal pin that has been hammered deep into the ground.

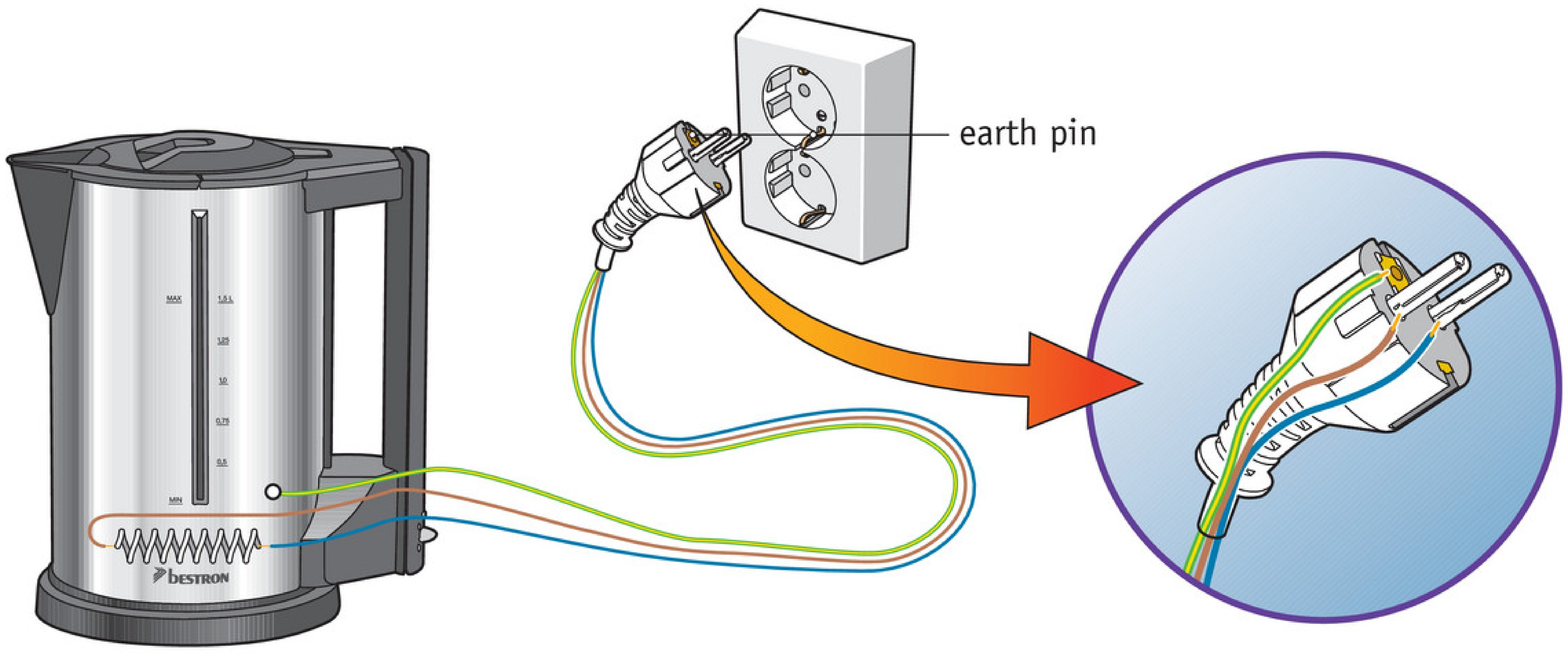


figure 8 This is how a kettle is earthed.

If the metal casing of the appliance becomes live, a substantial leakage current then goes into the ground via the earth wire. This means that the ELCB turns off power immediately. This therefore happens before anyone can touch the device.

Before earth leakage circuit breakers existed, the current to earth had to make the group's fuse blow. That did not always work: sometimes this 'leakage current' remained below 16 A and nothing happened. A modern ELCB may be tripped by a current of as little as 30 mA. This provides additional safety that cannot be ensured by a fuse.

PLUS HOW AN EARTH LEAKAGE CIRCUIT BREAKER WORKS

Figure 9 shows a schematic diagram of how a simple type of earth leakage circuit breaker works. The live wire and the neutral wire are connected to coils (S_1 and S_2). The same effect operates here as in the primary coil of a transformer: a current through a coil generates a magnetic field. The current I_1 through the live wire is normally identical to the current I_2 through the neutral wire, meaning that the two magnetic fields are equally strong.

The coils are wound so that the sense of current I_1 is opposite to the sense of current I_2. The direction of the magnetic field induced by a coil depends on the direction of the current through the coil. Because the magnetic fields are in opposite directions, they cancel each other out. There is then no *net* magnetic field and so no current flows through the detector coil S_3 and the circuit breaker does not respond.

If the currents are just a little bit different, their magnetic fields will be as well and so a net alternating magnetic field will be created in the iron ring. A small voltage will then be generated in the detector coil S_3. The voltage induced in the detector coil results in a small current going through the circuit breaker, which will then interrupt the current.

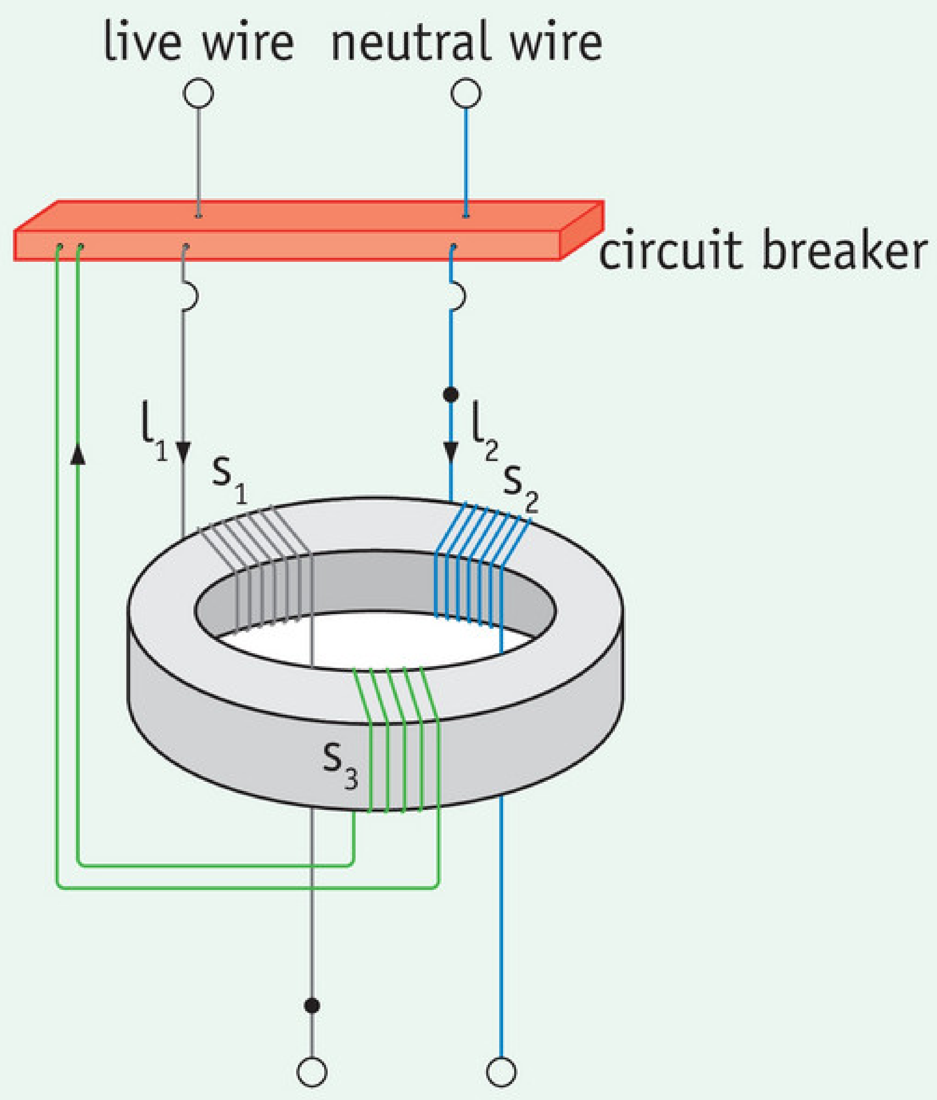


figure 9 This is what a simple earth leakage circuit breaker looks like schematically.

Practice the concepts using the *Flash cards*.

COURSE MATERIAL

1 Answer the following questions.

a Which two situations can cause the current in a group to become too high?
b Explain what has happened when a short circuit occurs in a device.
c How can you tell that a circuit breaker has switched off the power in the group?
d How does an earth leakage circuit breaker determine that the current needs to be switched off?
e In what situation does an earth leakage circuit breaker provide greater safety than a fuse?

2 Appliances with a metal casing (such as a washing machine or a fridge) are always earthed.

a Explain why it is important that the metal casing of a washing machine is earthed.
b Explain the path that the leakage current is discharged along in that case.
c How can you recognize an earth wire?
d Explain why there is no point earthing the outer casing of a double-insulated appliance.

IN PRACTICE

3 If you take hold of a 230 V wire, you will get a severe shock. Your hands may become sweaty from the fright.

a How would the sweat affect the contact resistance of your body?
b Because of the sweating, it will become more difficult to let go of the wire again. Explain why.

4 A fan oven has a heating element that heats the air (1450 W), a fan to distribute the hot air (80 W) and a grill (1300 W).

a Calculate the maximum current drawn by the fan oven.

b As well as the fan oven, the kitchen has a coffee machine (800 W), a fridge (100 W) and a dishwasher (1800 W). Suppose that all these appliances are connected to the same group and turned on at the same time.
Explain whether the group fuse will then be triggered.

c Write down one benefit and one disadvantage of installing a separate group for the fan oven.

★ 5 A brochure contains an advertisement for a cable reel (figure 10). It warns that the cable can only be used for a limited amount of power.

a Calculate the maximum current:
- when the cable is fully unwound.
- when the cable is still on the reel.

b Anne is using the cable reel to connect a 2.2 kW wood chipper to the mains.
Explain what could go wrong, if she does not unwind the cable fully first.

c How can you tell that the copper wire of the cable must be about the same thickness as the copper wire in the domestic electrical system?

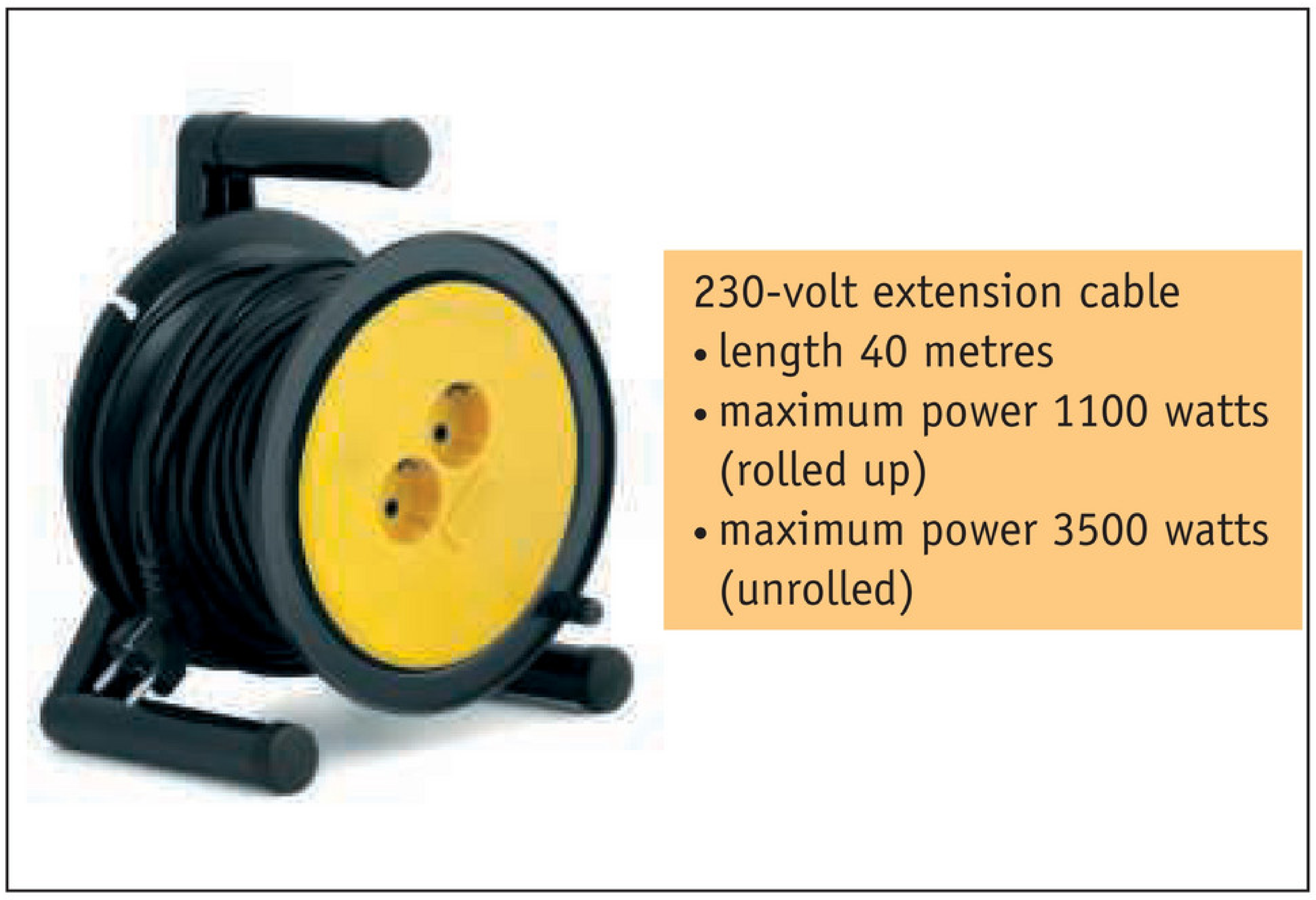


figure 10 An advertisement for a cable reel.

6 Three appliances are switched on in the kitchen of Peter's apartment: the washing machine, the electric oven and the fridge. There is a power failure when Peter switches on his kettle too.

a Note two possible causes for this power failure.

b The television in Peter's living room is still on.
Why is there no power failure there?

c Peter sees that the lever of one of the circuit breakers has flipped. When he pushes the lever up and releases it, it flips straight back down again.
What should Peter have done first?

7 David gets a shock when he touches his electric oven. A current of 8.25 A is running through the live wire at that moment and a current of 8.21 A through the neutral wire.

a Calculate the size of the leakage current in this situation.

b Explain if the earth leakage circuit breaker will switch off power.

c When the oven is repaired the following day, it turns out that the earth wire has come loose. As a result, the metal outer casing of the appliance was not earthed anymore. Explain why David would not have got a shock if the earth wire had been attached properly.

8 An electric shock can cause serious injuries. The level of risk depends both on the current and on the time that the current runs through your body for (figure 11).

a Within how long must an earth leakage circuit breaker turn off the power to limit the risk:
- at a current of 50 mA?
- at a current of 200 mA?

b The website www.veiligheid.nl states: "The earth leakage circuit breaker switches off when the leakage current is greater than 30 milliamps and continues for at least 20 milliseconds, thus making electrocution impossible."
Explain whether this statement is consistent with the information in figure 11.

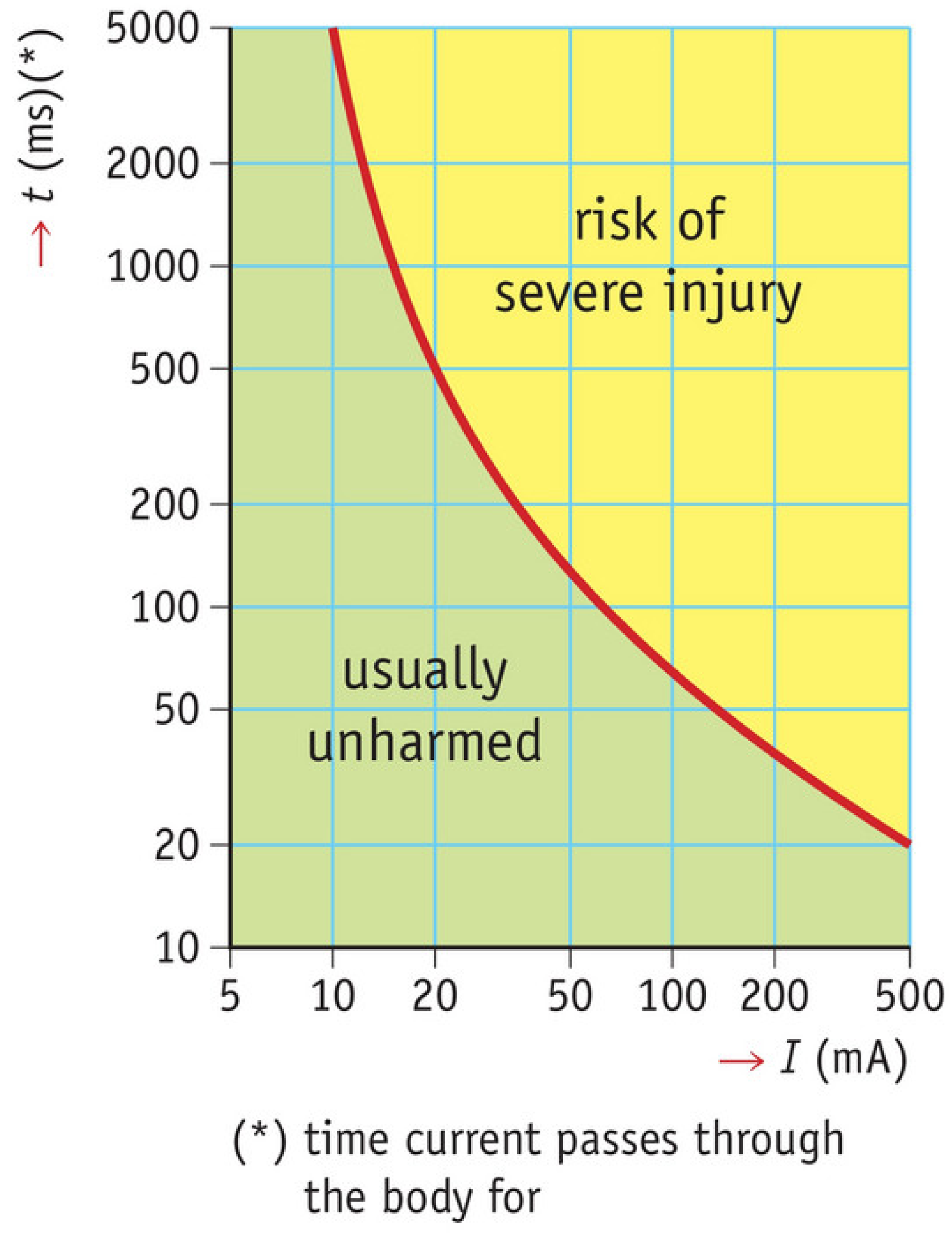


figure 11 The risk limits for electric shocks.

★ 9 Giles is checking if a socket is live. The neon bulb in the voltage detector lights up when he presses the back end of the voltage detector with his finger (figure 12).

a Is the current that runs through the neon bulb and his finger to the earth strong? How do you know that?

b Giles notices that the neon bulb lights up more brightly when he touches a water tap with his other hand.
Why does the current increase? Use the word 'resistance' in your explanation.

c Is the piping in Giles' house made of copper or plastic? Explain your answer.

figure 12 Testing a socket with a voltage detector.

Test what you know with *Test yourself*.

PLUS HOW AN EARTH LEAKAGE CIRCUIT BREAKER WORKS

10 Coils S_1 and S_2 in figure 9 have the same number of turns.

a Explain why this is important.

b Figure 13 shows two 'snapshots' of the net magnetic field arising in the iron ring when current I_1 is greater than current I_2.
Explain why the net magnetic field in the iron ring keeps changing direction.

c Explain why an induced voltage is now being created in the detector coil S_3. Use the term 'magnetic field' in your answer.

d The size of the induced voltage in the detector coil S_3 depends among other things on the *rate* of change of the magnetic field: if the field changes twice as quickly, the induced voltage will be twice as high.
In the Netherlands, the frequency of the alternating voltage is 50 Hz, but the island of Antigua uses 60 Hz at the same mains voltage.
Explain whether the earth leakage circuit breaker will respond more quickly under the same conditions in the Netherlands or on Antigua.

e Esther says, "If the alternating currents I_1 and I_2 in the earth leakage circuit breaker in figure 9 were replaced by direct currents of the same size, the earth leakage circuit breaker would respond to the same size leakage current."
Explain whether Esther is right or not.

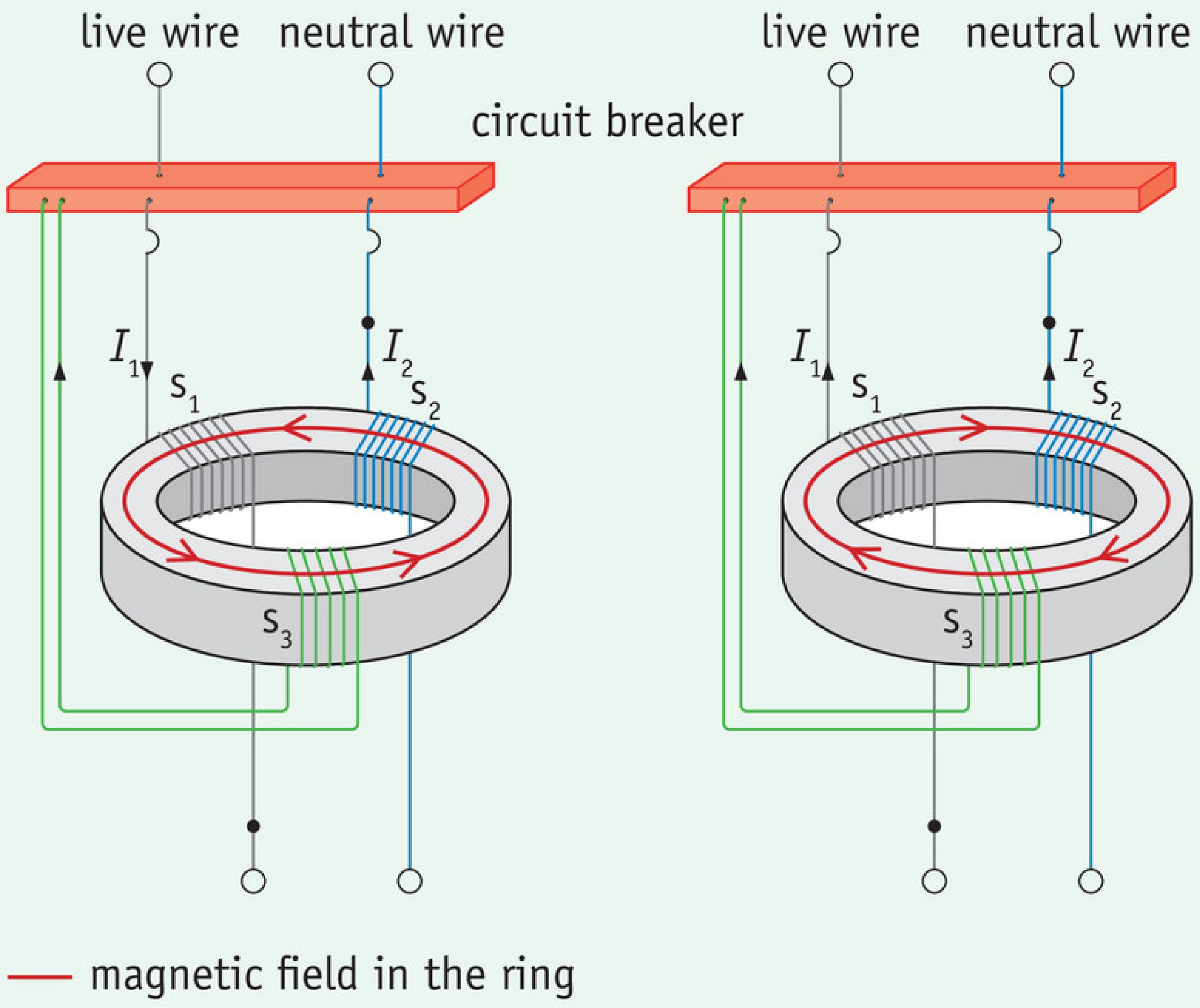


figure 13 The net magnetic field in the ring changes direction rapidly.

11

a Roy says, "If you replace the iron ring by a copper ring, the earth leakage circuit breaker would respond earlier because copper conducts the current much better."
Explain whether Roy is right or not.

b How would you have to modify the detector coil in figure 9 to make the earth leakage circuit breaker respond more quickly to the same leakage current?
Hint: you can compare the detector coil to the secondary coil in a transformer.

Experiments

EXPERIMENT 1 THE TRANSFORMER

30 minutes

Introduction

The voltage from a voltage source is often not right for a device – too high or too low. You have to use a transformer in such cases. A transformer lets you step the voltage up or down, while hardly any electrical energy will be lost.

Purpose

You are investigating the properties of a transformer.

Requirements

- ☐ power supply box
- ☐ soft iron yoke piece
- ☐ soft iron breech piece
- ☐ coil with 300 turns
- ☐ coil with 600 turns
- ☐ voltmeter or multimeter
- ☐ copper or aluminium rod
- ☐ wires

Doing the experiment and writing it up

- Build the simple transformer drawn in figure 1.
- Carry out the four experiments that are described below.
- For all the experiments, set the power supply box to 6 V (~ or =).

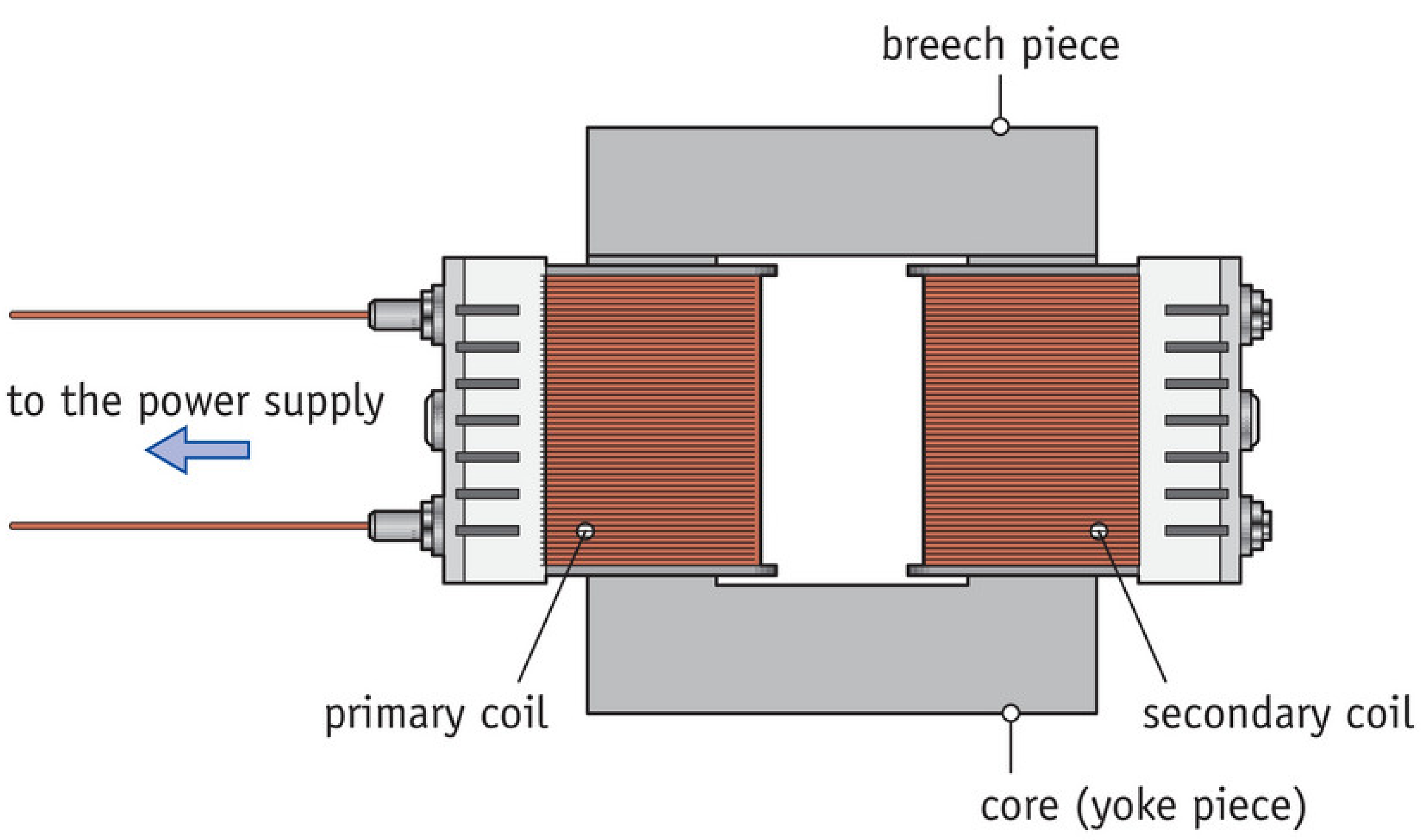


figure 1 A simple transformer.

Experiment 1

- Investigate whether it is possible:
  - to transform a direct voltage;
  - to transform an alternating voltage.

1 Write down your findings.

....

....

....

....

Experiment 2

- Investigate how you can step a voltage of 6 V upwards.

2 Which coil must you use as the primary coil and which as the secondary coil?

....

....

3 What will the (secondary) voltage be?

....

Experiment 3

- Investigate how you can step a voltage of 6 V downwards.

4 Which coil must you use as the primary coil and which as the secondary coil?

....

....

5 What will the (secondary) voltage be?

....

Experiment 4

- Investigate what happens if you remove the breech piece.

6 Does the (secondary) voltage change, and if so, how?

....

....

....

7 What happens if you replace the breech piece with a copper or aluminium bar?

....

....

....

....

- Your teacher will tell you which investigations you have to write up a report on.

EXPERIMENT 2 MEASURING USING AN ENERGY METER

30 minutes

Introduction
An energy meter lets you measure the energy consumed by an electrical device and its power. This measuring instrument is also known as an “energy costs meter”. Your teacher will give you the manual (or a link to it). Read it well before you start working.

Purpose
You are determining the power and energy consumption of various electrical appliances.

Requirements
- ☐ energy meter
- ☐ hairdryer
- ☐ stopwatch
- ☐ kettle

Doing the experiment and writing it up
WARNING
You will be working with a voltage of 230 V in this experiment.
So be careful. Follow your teacher’s instructions.

- Your teacher will tell you what measurements you have to make.

Measurement 1: The power of a hairdryer
- Insert the energy in a socket.
- Connect the device to the energy meter (figure 2).
- Determine the power consumed by the hairdryer at various settings.

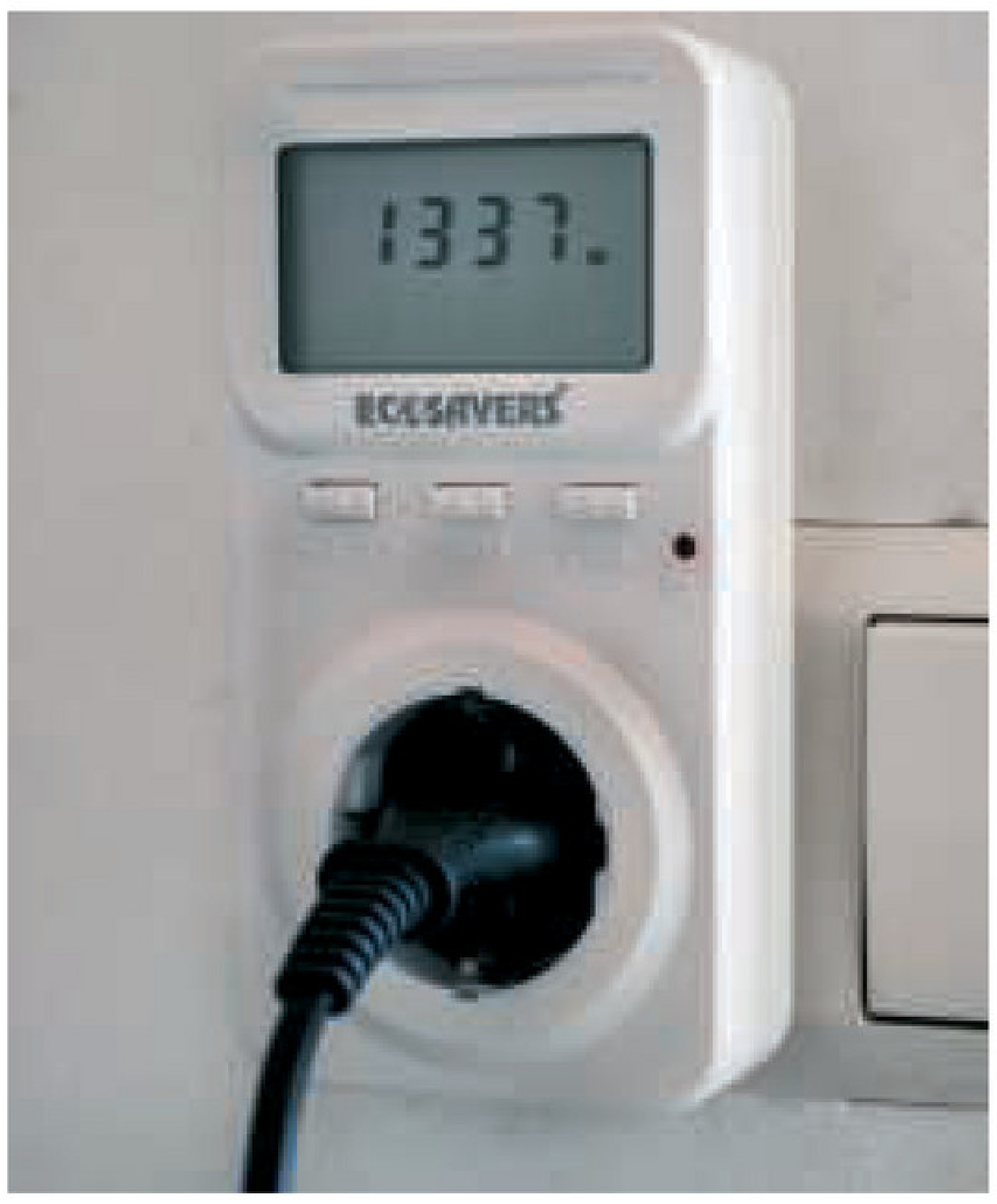


figure 2 This is how the power consumption of a hairdryer is measured.

1 Write down your measurement results.

....

....

....

....

2 Write down the power stated on the rating plate of the hairdryer.

....

3 Compare the power on the rating plate (Exercise 2) against the power measurements you have made (Exercise 1).
What conclusion can you draw?

Measurement 2: The energy consumption of a kettle

- Set the energy meter's electricity cost to € 0.23.
- Put half a litre of water in the kettle.
- Measure the amount of electrical energy that is needed to bring half a litre of water to the boil.

4 Make a note of:

- how long it took to bring the water to the boil;
- how much electrical energy the kettle consumed;
- how much this amount of energy would cost.

5 Calculate the energy consumption of the kettle using the power on the type plate and the period of time that you wrote down in Exercise 4.

6 Compare the calculated energy consumption (Exercise 5) against the measured energy consumption (Exercise 4).
What conclusion can you draw?

EXPERIMENT 3 AN INVESTIGATION INTO ENERGY SAVINGS

40 minutes

Introduction

Suppose that the packaging of a LED bulb makes a comparison against an energy-saving bulb. You can conclude from this that a LED bulb is at least twice times as economical as an energy-saving bulb (figure 3). You might wonder if this statement is correct.
How could you check this?

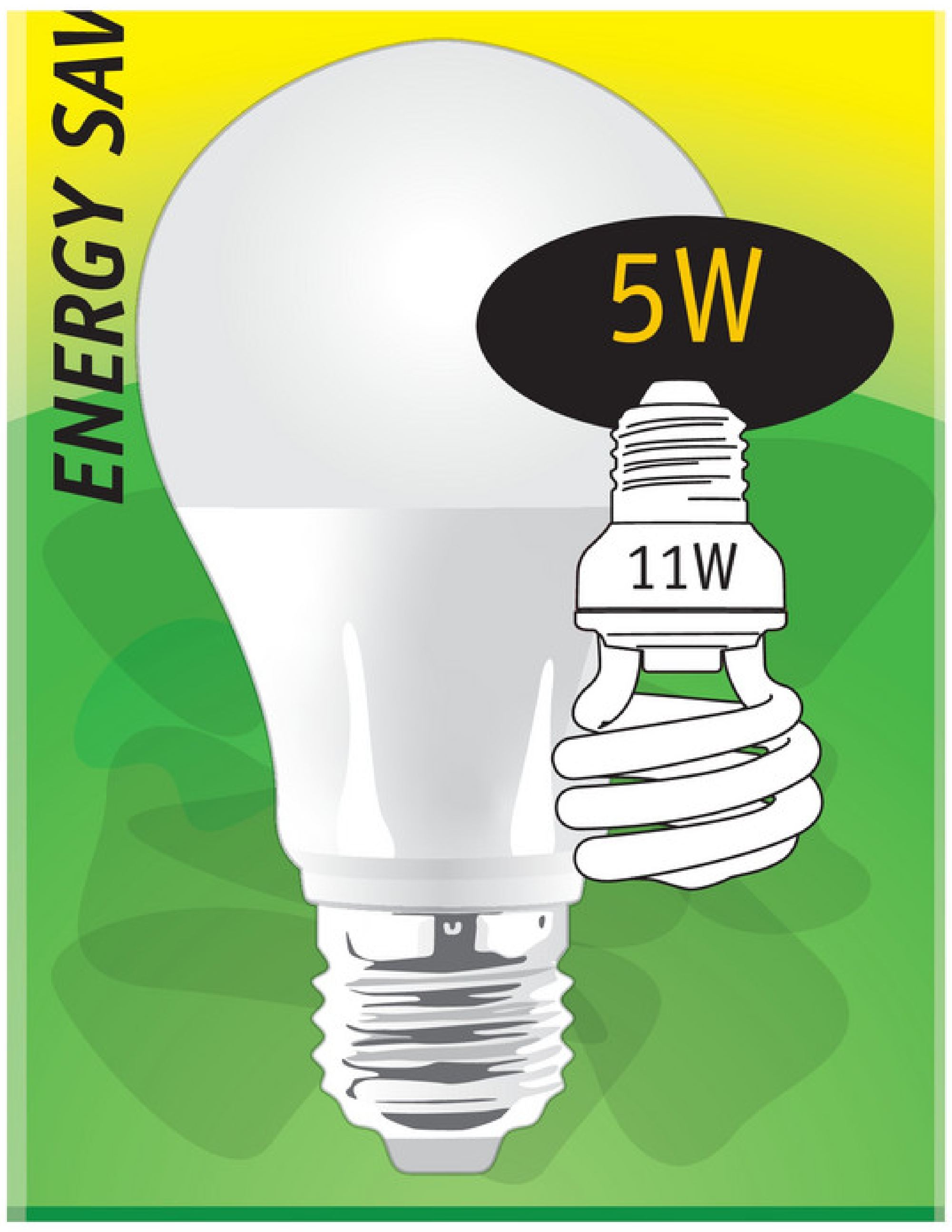


figure 3 Is the claim on the packaging correct?

Purpose

You are looking for an answer to the following research question:
Is a LED bulb at least twice as economical as an energy-saving bulb with the same light output?

Requirements

For this experiment, you have to think up for yourself what equipment you will need for it.

Doing the experiment and writing it up

- Think about how you can give the most reliable answer to the question. What will your experimental setup look like? What will you look up and what will you measure? How will you make sure that the measurements are repeatable and can therefore be checked and confirmed?

1 See the skills section on *Doing research*.
Make a work plan for this study.

- The work plans will be discussed with the rest of the class in the next lesson. If necessary, you can make improvements to your own work plan after that.
- Now carry out the experiment.

2 Write down all the measurements, calculations and results.

- Your teacher will tell you whether or not you have to write up a report on this experiment.

A supergrid for Europe

Renewable energy is getting more and more important in Europe. There is enough sun, wind and hydroelectric power to provide electrical energy for the whole of Europe. When the wind is not blowing in Scotland, the sun may well be shining in Spain. The only problem is how to get the energy to where it is needed. How can you transport renewable electricity from Spain to Scotland, when there is not enough in Scotland – or the other way around, when there is not enough in Spain? The European *supergrid* could be a solution.

One disadvantage of renewable energy sources is that their output varies a lot. One day there may be a strong wind and the wind turbines are rotating happily. But the next day, there may be hardly any wind and the wind turbines produce nothing at all. Solar energy is only produced during the daytime, and the output can be much higher in summer than in winter.

As a result of all these fluctuations, countries can have an excess of renewable energy at one moment and a shortage the next. This is an awkward problem because there still are no good ways of transporting the energy. Countries that have an excess cannot sell their surpluses to the rest of Europe. Countries that have a shortfall cannot import enough renewable electricity. And that is why they decide to use their old, polluting power stations again.

THE NORNED CABLE

The Netherlands and Norway are showing that things can also be done another way. In 2008, these two countries started to use the NorNed cable: a 580 km long, undersea high-voltage cable

between Feda in Norway and the Eems harbour in the Netherlands (figure 1). From that moment on, Norway has been able to supply electrical energy to the Netherlands, or the Netherlands to Norway – depending on what is the most advantageous.

Norway produces almost all its electricity as hydroelectric power from reservoirs. It is renewable and – often – very cheap. On the other hand, there may be major shortages in dry years. Electricity then suddenly becomes very expensive. There are large power stations in the north of the Netherlands. Although these do not produce sustainable power, they can supply electricity at any moment you choose.

There's a difference in energy consumption between the two countries too. At night, the Netherlands uses relatively little electrical energy, whereas energy consumption in Norway is rather high at night. The Netherlands still uses a lot of natural gas for heating, but Norway uses electric heating, which needs a lot of energy in the winter.

Because of these differences, both countries can benefit from the NorNed cable. During the daytime, Norway can export inexpensive and clean *hydroelectric power* to the Netherlands. At night, the Dutch power stations can operate continuously and supply current in the other direction to Norway. And in dry years, the Dutch current helps prevent the Norwegians from being faced with shortages and extremely high energy bills.

figure 2 Converter station at Eemshaven.

HVDC TECHNOLOGY

The high voltage power lines in Europe, and those in Norway and the Netherlands too, use alternating voltages. It is an excellent system, as long as the distances are not too large. That works fine up to 100 km or so, but problems arise with larger distances. So much energy is then lost in the cables that the energy transport costs more money than it brings in.

The NorNed cable uses a DC voltage. This is an HVDC connection, which combines *high voltage* with *direct current*. HVDC technology was chosen because DC voltages are more efficient for long distances than AC voltages. This makes transporting electrical energy for hundreds of kilometres profitable.

HVDC has disadvantages too. The alternating voltage of the normal electricity grid has to be specially converted into direct current for the NorNed cable. At the other end, this DC voltage has to be converted into back into an AC voltage. Technically, this is far from simple and requires a lot of equipment. The converter stations in Feda and the Eemshaven are each two football fields in size (figure 2).

figure 1 The NorNed cable.

NORNED TECHNICAL DATA:

- cable length 580 km, of which 420 km are in shallow water (at depths of up to 50 m) and 160 km at depths to a maximum of 410 m
- total mass of the cable: 47,000 tons
- mass of copper in the cable: 9,000 tons
- maximum voltages on the cable: + 450 kV en – 450 kV
- maximum capacity: 700 MW
- construction costs: 600 million euros

TECHNICAL PERFECTION

The NorNed cable has a capacity of 700 MW, which is enough to provide one million households with electrical energy. This 700 MW goes through two copper cables with a diameter of only 3.5 cm. The cable also has insulation material, shielding and sealing (figure 3). Inside the cable, the temperature gets up to 50 °C but on the outside it reaches a maximum of 35 °C.

A lot of advanced technology is used in the NorNed connection. That is why the connection is sensitive to faults. The cable had faults ten times in the first two years, sometimes for months at a time. There were several causes of these faults: broken cables, short circuits, defective components, software issues.

The teething troubles seem to have been overcome now. Economically, the cable has been a great success from the beginning. The 600 million euros in construction costs had almost been earned back by 2014, just six years after commissioning. Nobody had expected this beforehand.

"So we have to invest anyway – the question is then about the best way to spend our money."

THE FUTURE: A SUPERGRID?

The success of the NorNed cable is not the only one of its kind. There are several other countries in Europe that have HVDC connections, such as France and Great Britain (2000 MW, 73 km), Greece and Italy (500 MW, 313 km) and Poland and Sweden (254 km, 600 MW).

According to some energy experts, this is only the beginning. A single cable can transport up to 7000 MW over more than 2000 km using existing HVDC technology: the distance between Edinburgh in Scotland and Seville in southern Spain. Technically, this makes it possible to connect all the countries in Europe into a single large European super-network.

Such a *European supergrid* is good news for producers of sustainable energy. Europe wants to generate a large part of its electricity renewably. The supergrid makes this possible because renewable energy then can be imported and exported easily: this lets the national energy companies compensate for peaks and troughs in output much better.

But it is nowhere near that far yet. To start with, a lot of money is needed. The estimated cost of a supergrid is more than 125 billion euros. That is not an amount that can easily be found by the countries in Europe. Agreements will have to be made about the use and management, which is not very simple when so many countries are involved.

Despite this, Tara Connolly, an energy lobbyist with the environmental organization Greenpeace, is optimistic: "A large proportion of the grid we have now is forty years old and will have to be replaced shortly. So we have to invest anyway – the question is then about the best way to spend our money." She would choose a European supergrid without hesitating. So let's wait and see if Europe agrees with her.

figure 3 The cable consists of two copper conductors with insulation material, shielding and sealing.

EXERCISES

1 Calculate, using the data in the text:

a the total current that goes through the copper conductors when the maximum capacity of the NorNed cable is being used.

b the amount of electrical energy in kilowatt-hours that the NorNed cable can transport in one day from the Netherlands to Norway (or the other way round).

2 HVDC (high-voltage direct current) technology has been used for the NorNed cable.

a Why are HVDC cables used for long-distance energy transport instead of normal high voltage lines?

b Why is HVDC unsuitable for the normal electricity grid, which distributes electrical energy to cities and villages?

3 It would be technically possible to store a surplus of wind energy from Germany temporarily in Norwegian reservoirs. There are plans to set up an HVDC connection between Germany and Norway.

Explain:

a how you can store surplus renewable energy in a reservoir.

b why the storage capacity is limited and not always constant.

c how you can extract the stored energy from the reservoir again.

Course material overview

1.1 GENERATING ELECTRICAL ENERGY

REMEMBER

- In a power station, steam is produced by heating water. The steam drives a turbine that is connected to a generator. The generator produces alternating current.
- When a magnet moves regularly back and forth inside a coil, an alternating voltage (an induced voltage) is created across the terminals of the coil. This phenomenon is called induction.
- In a dynamo, a coil is fitted around a U-shaped core of soft iron. Making a magnet rotate inside the U-shaped core keeps magnetizing the soft iron differently and so an induced voltage is produced across the terminals of the coil.
- Using the formula $E = P \cdot t$, you can calculate the energy (E), the power (P) and the time (t). You can also write the formula as $P = \frac{E}{t}$
- It is often more convenient to write large numbers using prefixes.

CONCEPTS

alternating voltage
A voltage that continuously changes from positive to negative in a wave pattern, such as the mains voltage.

coil
An insulated, wound-up copper wire.

consuming electrical energy
Drawing electrical energy from the mains, as done by electrical appliances (with the electrical energy being converted into other forms of energy).

electrical power
1 The amount of electrical energy per second that a power station or turbine supplies to the network (also known as its "capacity").
2 The amount of electrical energy per second that an appliance consumes or draws from the network (also known as its "rating").

field lines
Lines that show the direction of a magnetic field.

generator
The part of an electricity power station that works like a large dynamo: it converts kinetic energy into electrical energy.

induced voltage
An alternating voltage that is created by means of a changing magnetic field.

induction
Producing an alternating voltage across the terminals of a coil by means of a changing magnetic field.

magnetic field
The zone within which a magnet exerts forces.

power station
A building where large amounts of electrical energy are generated.

soft iron
A form of iron that can be magnetized and demagnetized quickly.

supplying electrical energy
Passing electrical energy to the electricity grid, as done by power stations, wind turbines, solar panels, etc.

turbine
The component of a power station that consists of a shaft onto which a large number of blades are attached. Because steam is forced up against the blades, the turbine's shaft rotates.

1.2 TRANSPORTING ELECTRICAL ENERGY

REMEMBER

- In high-voltage cables, the amount of heat generated can be reduced by using high voltages (380 kV). After transportation, the voltage is reduced to 230 V in two steps.
- A steady voltage that does not change is called a direct voltage. An alternating voltage is one that changes several times a second from a positive voltage to a negative voltage.
- A transformer consists of a primary coil, a secondary coil and a soft iron core. Transformers only work on alternating voltages.
- The following formula applies for the relationship between the primary and secondary voltages in the transformer: $\frac{U_p}{U_s} = \frac{N_p}{N_s}$

CONCEPTS

effective voltage
The ‘average’ value of an alternating voltage. When you do calculations with alternating voltages, for example to work out the power, you always use the effective voltage.

electromagnet
An electrical component such as a coil that behaves like a magnet when an electric current is passed through it.

energy loss
The fact that electrical energy is lost during transport because a proportion of the energy gets converted into heat.

frequency
The number of times per second that the wave pattern of the voltage repeats.

ideal transformer
An imaginary transformer in which no electrical energy is lost: the power consumption is the same as the output.

mains voltage
An effective voltage of 230 V, as used in the home.

polarity
A term for the direction of the voltage. If the positive and negative terminals are swapped (so that the direction of the current is reversed), the polarity of the voltage changes from positive to negative.

primary coil
The part of a transformer that the electrical energy from the mains goes into. An alternating current runs through it.

secondary coil
The part of a transformer that provides electrical energy to an appliance.

transformer
A device that can convert an alternating voltage into a higher or lower alternating voltage using two coils and a soft iron core.

1.3 ELECTRICITY IN THE HOME

REMEMBER

- You calculate the total current in a group by adding up all the currents in the various branches. As a formula, this is $I_{tot} = I_1 + I_2 + I_3$
- Various kinds of wires are used in a domestic system. The brown wire is the live wire. There is an alternating voltage of 230 V on this wire. The blue wire is the neutral wire. There is no voltage on it. The black wire is a switch wire. It will only be live when the switch is 'on'.
- You can use the formula $P = U \cdot I$ to calculate the power (P), the voltage (U) and the current (I).
- You calculate the total power in a group by adding up all the power ratings (of the devices that are on) in the various branches. As a formula, this is $P_{tot} = P_1 + P_2 + P_3$. If you know the total current and the voltage, you can work out the total power using the formula $P_{tot} = U \cdot I_{tot}$
- 1 kWh equals $3.6 \cdot 10^6$ J.

CONCEPTS

domestic system
The network of electric wires running through the walls and ceilings of a home, from the meter cabinet to the sockets and other connections.

group switch
A switch that lets you turn the voltage off for all the sockets and light fittings in a group in one go.

kWh meter or energy meter
A meter that measures the consumption of electrical energy in a house. It is also called a 'kWh meter' because the consumption is charged per kWh (kilowatt-hour).

live wire
Brown electrical wire on which there is an alternating voltage of 230 V.

neutral wire
Blue electrical wire that completes the circuit. There is no voltage on this wire.

switch wire
Black electrical wire running from a switch to a device, only live when the switch is in the 'on' position.

1.4 ELECTRICITY AND SAFETY

REMEMBER

- If the current in a group gets too high because too many devices are running on it at the same time, this is called an overload. When the current is able to take a different path with lower resistance, you call that a short circuit.
- Dangers of electricity are:
  - currents that are too high through the electrical wiring can cause fires;
  - you can get a shock when a current passes through your body.
- Group fuses and circuit breakers turn the current in a group off when the current drawn by the group becomes too great.
- A double-insulated device has normal insulation around the components that the current passes through, plus a second insulating layer.
- An earth leakage circuit breaker measures the current that goes into a group and the current coming back out of it. If the difference is greater than 30 mA because there is a leakage current somewhere, the earth leakage circuit breaker turns the current off.
- If an appliance has a metal casing that is live, the earth connection makes sure that a current runs to earth, which will trigger the earth leakage circuit breaker to turn the current off.

CONCEPTS

body resistance
The resistance of your body against electrical currents (the higher the resistance, the smaller the current).

circuit breaker
An electronic fuse. When the circuit breaker turns the current off, a small lever flips up.

contact resistance
The resistance at the points where the current enters and exits the body (the greater the resistance, the smaller the current).

double insulation
A way of insulating appliances in which two layers of insulation are used: one around the components that the current is passing through and one on the outside of the appliance.

earth leakage circuit breaker
A device that compares the current in the live wire against the current in the neutral wire. If the difference is greater than 30 mA, the earth leakage circuit breaker will turn off the power. There is then no longer a leakage current.

earth wire
A copper wire with green-and-yellow striped insulation that connects the socket's earth connection to a pin that has been driven into the ground.

group fuse
A device that turns the current off if the current in the group goes above 16 A.

overloading
Running too many devices from a single group, so that the total current is greater than 16 A.

short circuit
A fault in a circuit that allows the current to find an easier path from the live wire to the neutral wire (that is, one where the resistance is much too low).

Go to the *Flash cards* and the *Diagnostic test*.

2 Forces

MUSCLE STRENGTH VERSUS GRAVITY

Forces play an important role in your life. Whenever you walk, run or cycle, take a bite out of an apple or even just breathe, your muscles have to exert forces for you. You can also use your muscle strength to overcome the force of gravity, for example when you climb a rock.

What do you already know about forces?

LEARNING OBJECTIVES

1. You can explain how the speed changes in uniform, accelerating and decelerating motions.
2. You can determine the mass of a quantity of a substance and give it in kilograms or grams.
3. You can explain the difference between mass and weight.

In Parts 1 and 2 of Nova, you already learned some facts about motion, mass and weight. You will need this knowledge again when you start this chapter. If you want a quick check of what you can remember, do the following exercises.

EXERCISES TESTING YOUR PRIOR KNOWLEDGE

1

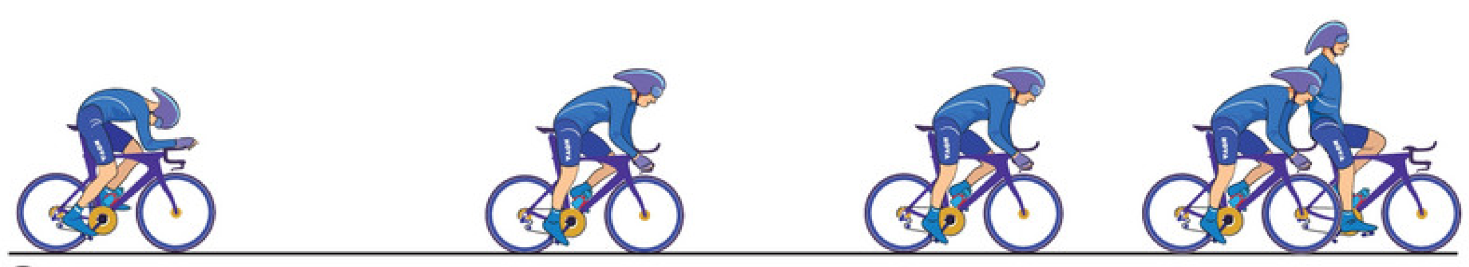
Look at the illustrations of three motions and the three terms.
Draw a line from each illustration to the correct term.

a

1 deceleration

b

2 acceleration



c

3 uniform motion

2

Look at the three types of motion and the three descriptions.
Draw a line from each motion to the correct description.

A	uniform motion	1	a motion in which the speed keeps decreasing
B	acceleration	2	a motion with a constant speed
C	deceleration	3	a motion in which the speed keeps increasing

3

Convert.

0.980 kg = ... g

125 g = ... kg

28 mg = ... g

0.375 g = ... mg

4 Mass and weight are two different things in physics. The *mass* / *weight* says how much substance there is in an object. The *mass* / *weight* is the force that the object exerts on your hands (when you lift it up) or on the floor (when you put it down).
The value of the *mass* / *weight* depends not only on the *mass* / *weight* but also on the strength of gravity. In everyday life, you don't see any difference between mass and weight because gravity is equally strong everywhere on the Earth. But that's no longer true if you leave the Earth.
Astronauts are well aware that their *weight* / *mass* can vary enormously, whereas their *weight* / *mass* stays the same. Objects have less *weight* / *mass* on the Moon than they do on Earth.

If you want to know whether you have the prior knowledge you need for this chapter, do the *Prior knowledge test* online. You will also find videos there on the key learning goals for this chapter.

1 Types of forces

LEARNING OBJECTIVES

2.1.1 You can explain what changes a force can bring about.
2.1.2 You can name and describe five different types of forces.
2.1.3 You can measure the size of a force.
2.1.4 You can calculate the force of gravity exerted on a mass.
2.1.5 You can use a force scale to draw a force to scale.
2.1.6 You can determine the centre of gravity of an object.
PLUS 2.1.7 You can work out where the centre of gravity of an object is.

Examples of ‘forces’ are not just muscle strength but also resistance, gravity and so forth. You can recognize forces from the effect they have. You can’t see the force exerted by the wind but you can see a tree bending in a strong wind and swaying backwards and forwards.

RECOGNIZING FORCES

When a **force** is exerted on your body, you can often feel it, for example if somebody gives you a shove or if it is very windy. You cannot see or feel forces that are exerted on other people or objects. You can only see the change caused by the force. You can work out that a force has operated (or is still operating) from that change.

Forces can change the motion of an object. In a volleyball game, that is happening all the time. The speed of the ball increases when a player smashes it. The speed is reduced when a player ‘spikes’ a hard shot. The direction of the ball changes when players tap or hit it.

Forces can also change the shape of an object. You see this for instance when an archer draws a bow or when a gymnast lands on the trampoline again after a jump. In ball sports, the ball deforms every time it is hit, although that is difficult to see with the naked eye (figure 1).

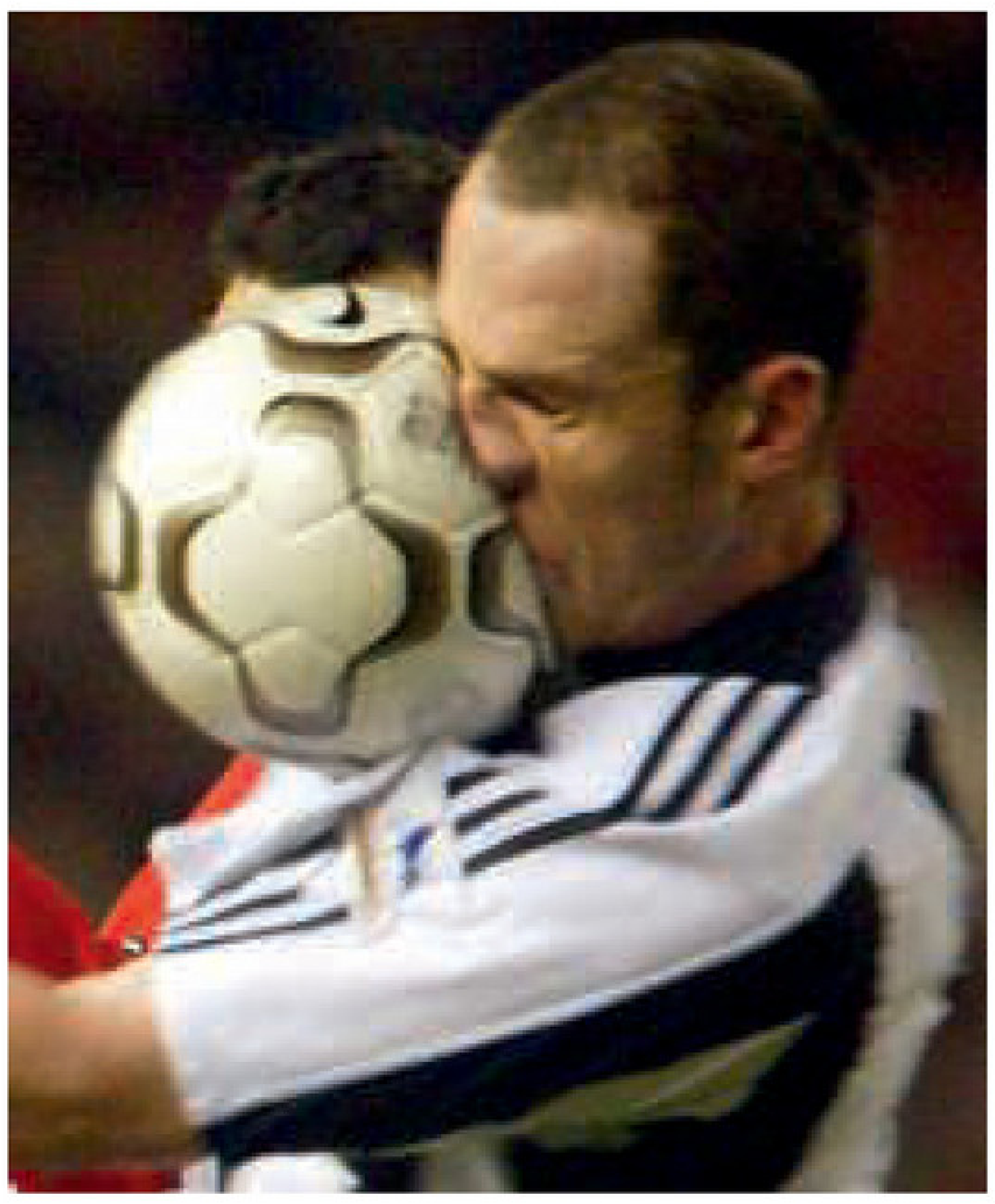


figure 1 The ball’s deformation is elastic. That is not necessarily the case for the player’s nose.

A deformation can be **elastic** (from the Greek *elastos* = stretchy) or **plastic** (from the Greek *plasma* = moulding). In an elastic deformation, the object regains its original shape once the force is no longer being exerted. You can see that in a mattress or a bicycle tyre. In a plastic deformation, the shape of the object is changed permanently, as in clay.

TYPES OF FORCES

There are all kinds of forces, such as muscular strength, springiness, gravity and magnetism. You refer to all these forces using the symbol F (for '*force*'). To show which force you are talking about, you add the type of force in small letters, for example F_{muscle} for muscle strength, F_{resist} for resistance and so forth.

Some examples of forces:

- When you throw a softball, your hand exerts a force on the ball. When you cycle, your feet exert forces on the pedals. In both cases, the forces come from your **muscular strength**. These forces are created when the muscles in your body contract.
- When you press the button on a ballpoint pen, you feel the coil spring push back against your thumb via the button (figure 2). This force is the **resistance** or **resilience**. When you extend or compress a springy material, you can feel it resisting. The resistance disappears again when the material returns to its original shape.

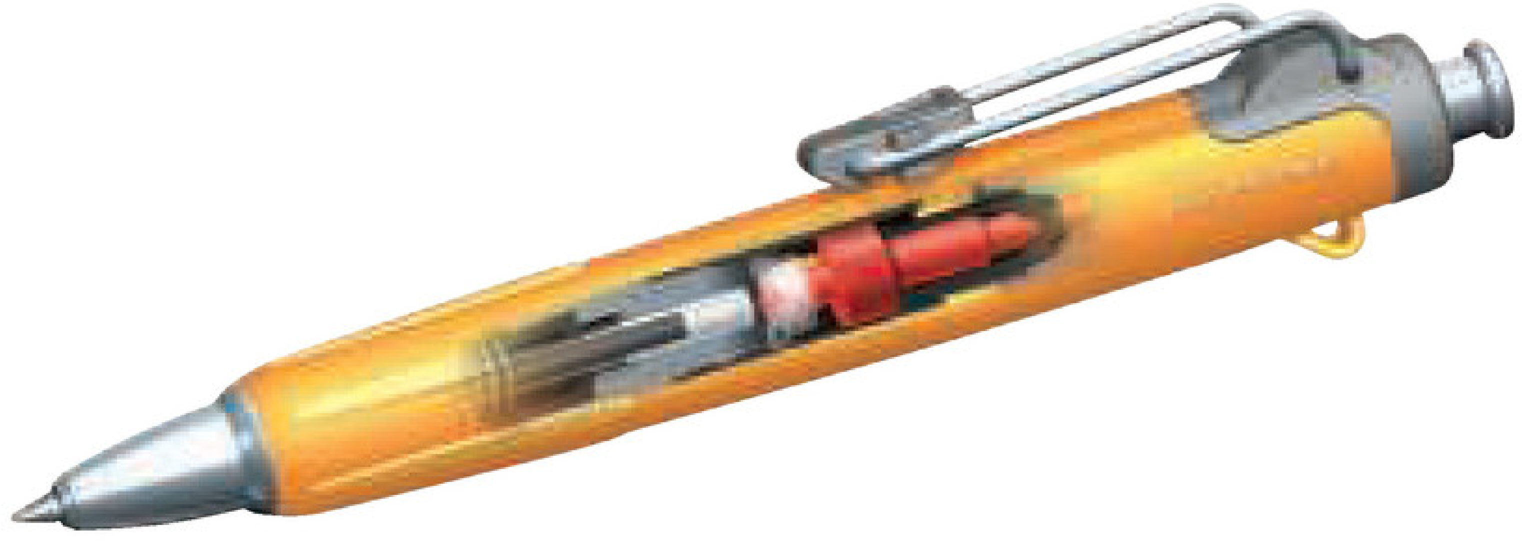


figure 2 You feel the resistance when you push the button on a ballpoint pen.

- If you pull a rope tied to a sledge in the snow, a force is created in the rope. This force is called **tension**.
- If you lift up your school books, you can feel how heavy the books are. If you then let go of the books, they fall straight to the floor. This is the effect of **gravity**. Gravity is the force that pulls you and everything around you downwards.
- If you hold two bar magnets close to each other, you can feel the **magnetic forces** at the poles (the ends). A north pole and a south pole attract each other, but two north poles repel each other, as do two south poles. This repulsion explains why the top magnet in figure 3 keeps on floating.

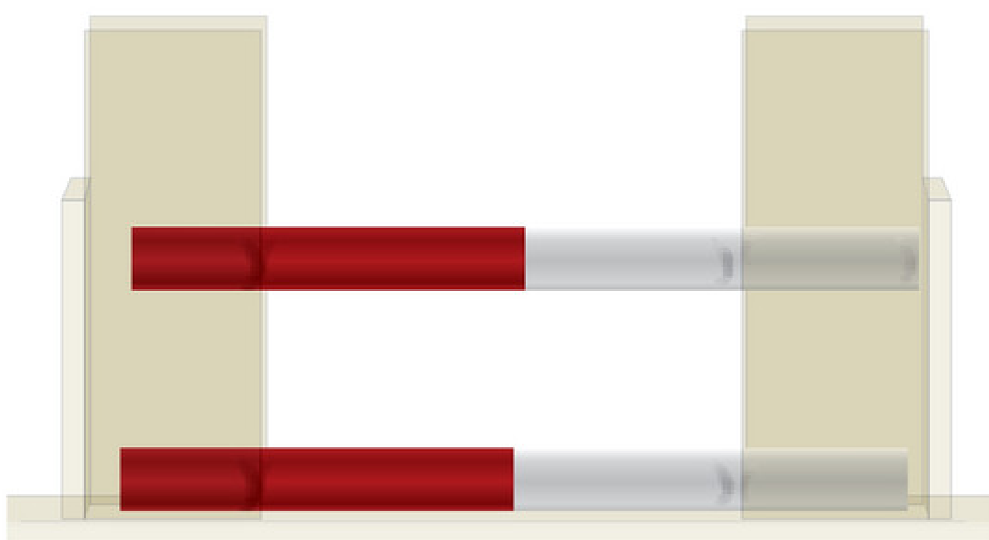


figure 3 Magnetic force: the two magnets repel each other.

MEASURING FORCES

You can measure forces with a **dynamometer**. A dynamometer contains a helical spring. The greater the force pulling on the dynamometer, the further the spring is stretched (figure 4). For measuring large forces, you use a dynamometer with a stiff spring. For measuring small forces, you use a dynamometer with a flexible spring. There are also dynamometers that you have to push in.

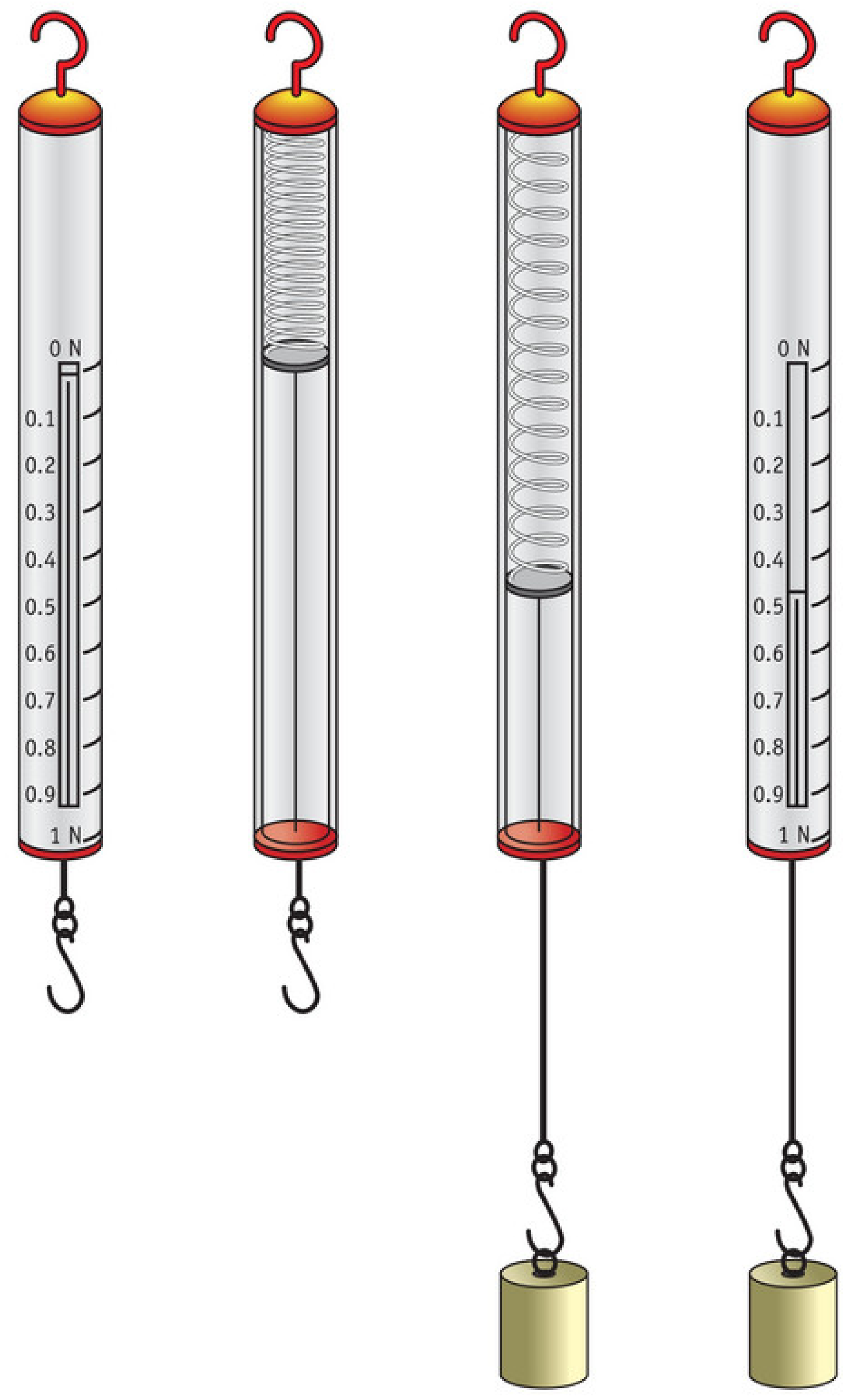


figure 4 How a dynamometer works.

A dynamometer as a scale that is graduated in newtons. The newton (N) is the unit that is used for measuring all forces, from the attractive force between two magnets to gravity on the Earth's surface. This unit is named after the English physicist Sir Isaac Newton (1642–1727).

On the Earth, there is a simple relationship between gravity and the mass of an object. To determine the force of gravity on an object, you have to multiply the mass by 9.8. You can write this calculation rule out as a formula using letters:

$$F_g = m \cdot g$$

where:
- F_g is the force of gravity in newtons (N);
- m is the mass in kilograms (kg);
- g is the gravity on the Earth's surface in newtons per kilogram (N/kg).

On Earth, g is 9.8 N/kg (it is actually 9.81 N/kg, but you don't need to be so precise in this chapter). The value of g is very different on other planets and moons. A dynamometer on the Earth's moon would show 1.6 N if a rock with a mass of 1.0 kg was hanging from it. The value of g there is only 1.6 N/kg, about one sixth of the value on Earth. See also the overview in table 1.

table 1 The strength of gravity on various bodies in the Solar System.

body	value of g (N/kg)
Earth	9.8
Moon	1.6
Mars	3.7
Mercury	3.7
Titan	1.4
Venus	8.9

DRAWING FORCES

A force has a magnitude, a direction and a point of application. A variable with these properties is called a **vector**. A vector is drawn as an arrow. That applies for forces too.

- The length of the arrow gives the magnitude of the force.
- The direction of the arrow shows the direction of the force.
- The point where the arrow starts shows where the force is being exerted.

When you are going to draw in forces, you first decide on a **force scale**. For example, 1 cm $\triangleq$ 5 N. That means that an arrow 1 cm long represents a force of 5 N. A force of 15 N drawn using this scale would then be an arrow 3 cm long.

Always think carefully about where you draw the arrow from. If you want to draw in the muscular force in figure 5, the arrow should start at the point where the hands are pushing against the boat: that is the point of application.

figure 5 Muscular strength exerted on a boat.

THE CENTRE OF GRAVITY

Gravity applies at all points on an object. You should therefore really be drawing lots of small vectors everywhere on the object, but that is not practical. Instead, you draw a single force from the **centre of gravity** C. That one force from C has the same effect as all the small gravitational forces combined. If an object has a simple shape, for example a sphere or a cube, the centre of gravity is at the centre of the object.

You can find the centre of gravity of an object by balancing the object on your index finger. If the object is balanced, that means your finger is directly under C. Of course, you can balance the object on something else too, as the surfer in figure 6 shows.

figure 6 The surfboard's centre of gravity is directly above the surfer's head.

PLUS DETERMINING THE CENTRE OF GRAVITY

In simple, symmetrical shapes such as a circle or rectangle, the centre of gravity is precisely in the middle. For more complex objects, you determine the centre of gravity as follows:

- Hang the object up. Use a weight on a string to draw a line l perpendicularly downward from the point it is hanging from.
- Hang the object up again by a different point. Draw a perpendicular line m downwards from this second point as well.
- The lines l and m cross at C. C is the centre of gravity (figure 7).

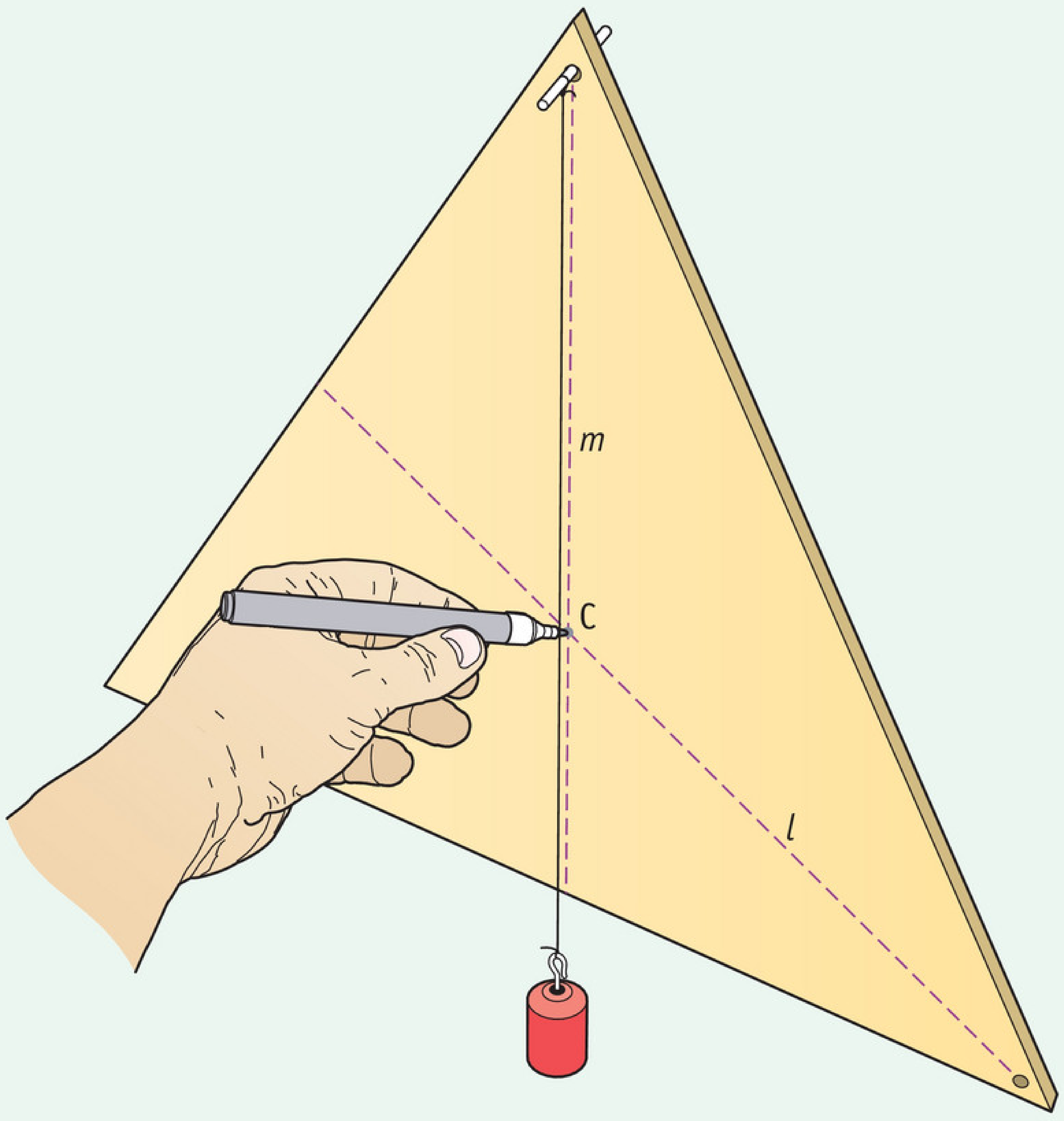


figure 7 How to determine the centre of gravity.

Practice the concepts using the *Flash cards*.

COURSE MATERIAL

1 Answer the following questions.

a How can you see that a force is being exerted on an object?
b What is the difference between elastic and plastic deformation?
c How large is the force of gravity on an object with a mass of 10 kg?
d What is meant by 1 cm $\triangleq$ 15 N?

2 You can draw a force as an arrow.

a What does the direction of the arrow show?
b What does the point at the start of the arrow show?
c What does the length of the arrow show?

IN PRACTICE

3 For each of the following situations, write down:

- whether the deformation is elastic or plastic;
- the name of the force that has caused the deformation.

a Marie flops down on a nice soft two-seater sofa.

b A tightrope artist walks along a rope that has been pulled tight.

c A plumber puts a bend in a copper tube.

d A pole vaulter hangs from a bent pole (figure 8).

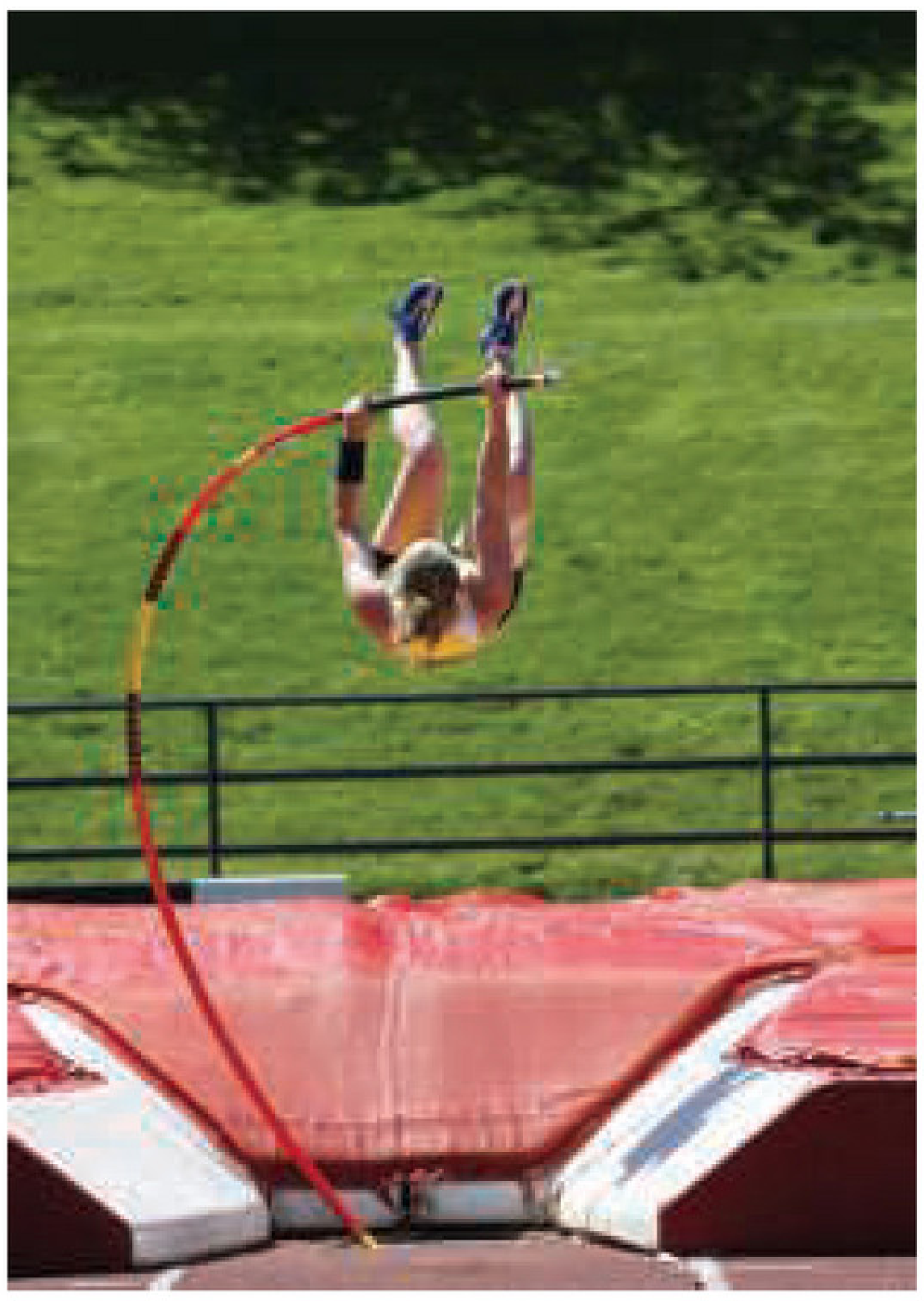


figure 8 Which forces are playing a role here?

4 Ewan is stretching an elastic rope to train his arm muscles (figure 9).

a The force that makes the elastic rope stretch a lot is ....

b The force that the elastic rope exerts on Ewan is called ....

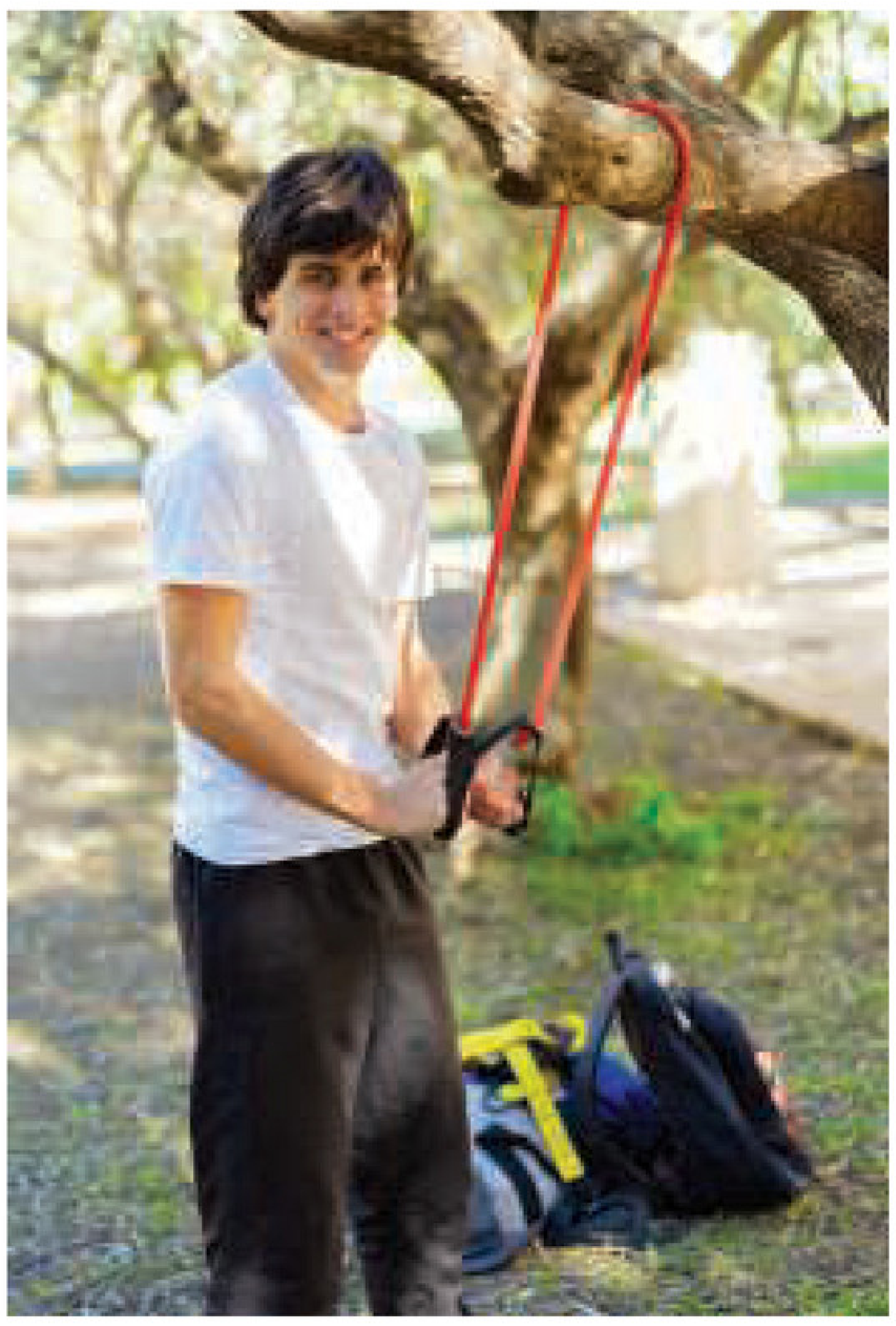


figure 9 Ewan is training his arm muscles.

5

In figure 10, draw the following forces. Use a force scale of 1 cm $\triangleq$ 100 N.

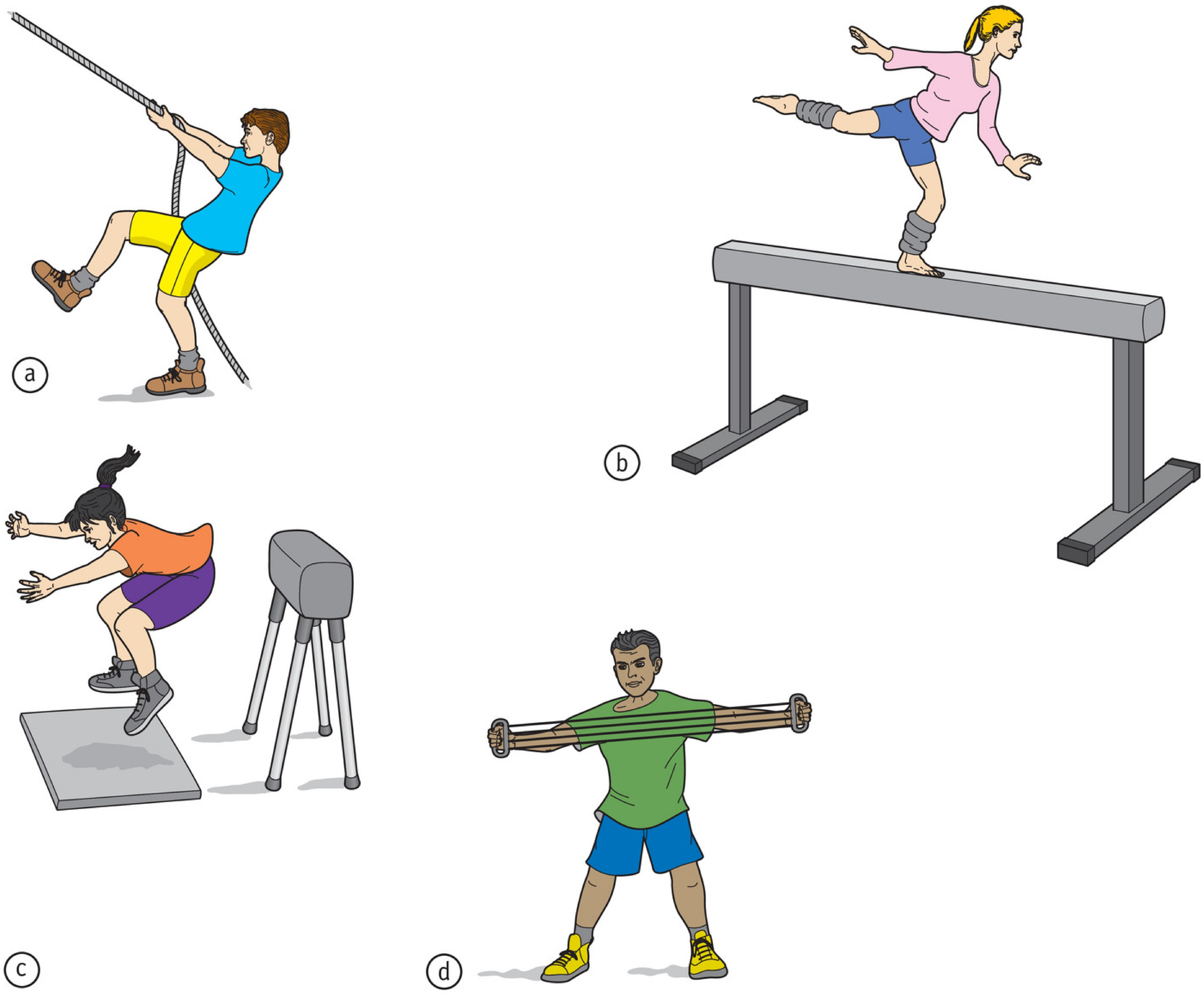
a the force of 400 N that Jake is applying to pull the rope (a)

b the force of 450 N that Anthea's foot is exerting on the beam (b)

c the force of 500 N that the Earth is exerting on Rosemary (c)

d the two forces of 150 N that the chest expander is exerting on Pete (d)

figure 10 Four forces.



6

Figure 11 shows the force that Steven is exerting on the wall with his hand. What force scale has the artist used:

a if the force on the wall is 46N?

b if the force on the wall is 69 N?

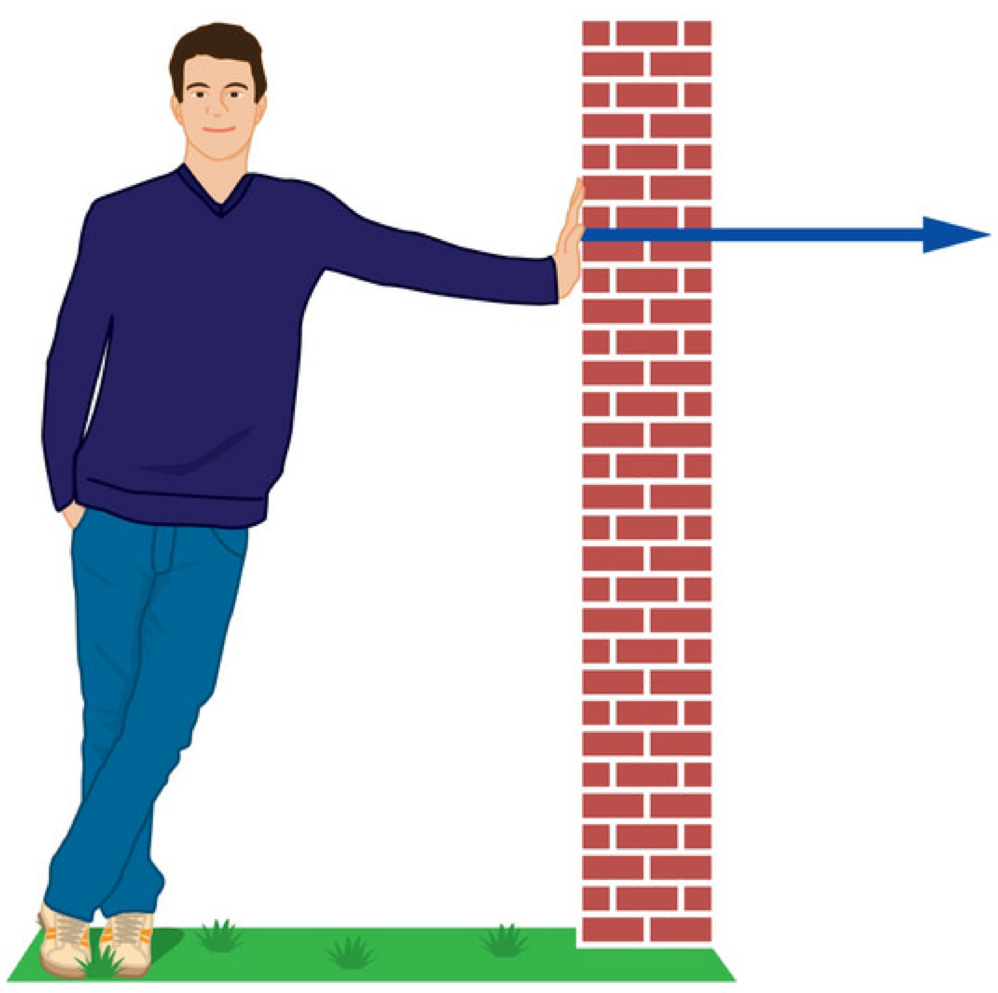


figure 11 The force of the hand on the wall.

7 Figure 12 shows two gymnasts who are struggling against gravity.

a Calculate the magnitude of the forces due to gravity on Lisa and on Ian.

b Draw in the force due to gravity in each drawing as an arrow.
Use a force scale of 1 cm ≙ 200 N.

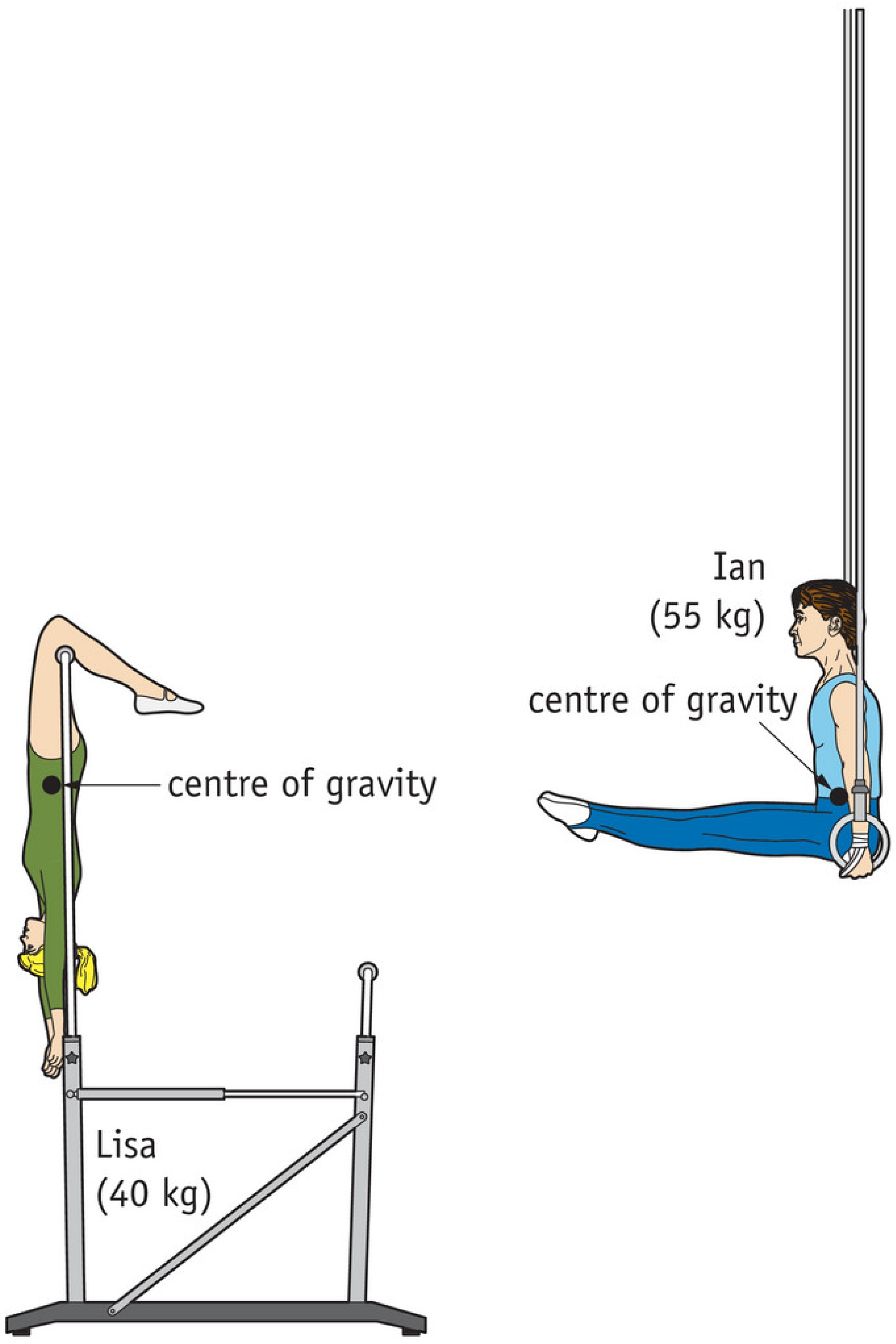


figure 12 Lisa and Ian fighting against gravity.

★ 8 On 21 July 1969, Neil Armstrong became the first person to walk on the Moon. At that point, his mass including his spacesuit was 160 kg.

a Calculate the gravitational force exerted on Neil Armstrong during that first moonwalk.

b Work out in which situation the force exerted on Armstrong due to gravity was greatest: on the Moon wearing his spacesuit or on Earth without his spacesuit.

9 A box is sticking out over the edge of the table (figure 13). The box hasn't fallen off the table, though.

a In the figure, colour the supporting surface of the box in red.

b In the figure, colour the part of the box where its centre of gravity is in blue.

c How could you make sure that the centre of gravity is in this part of the box?

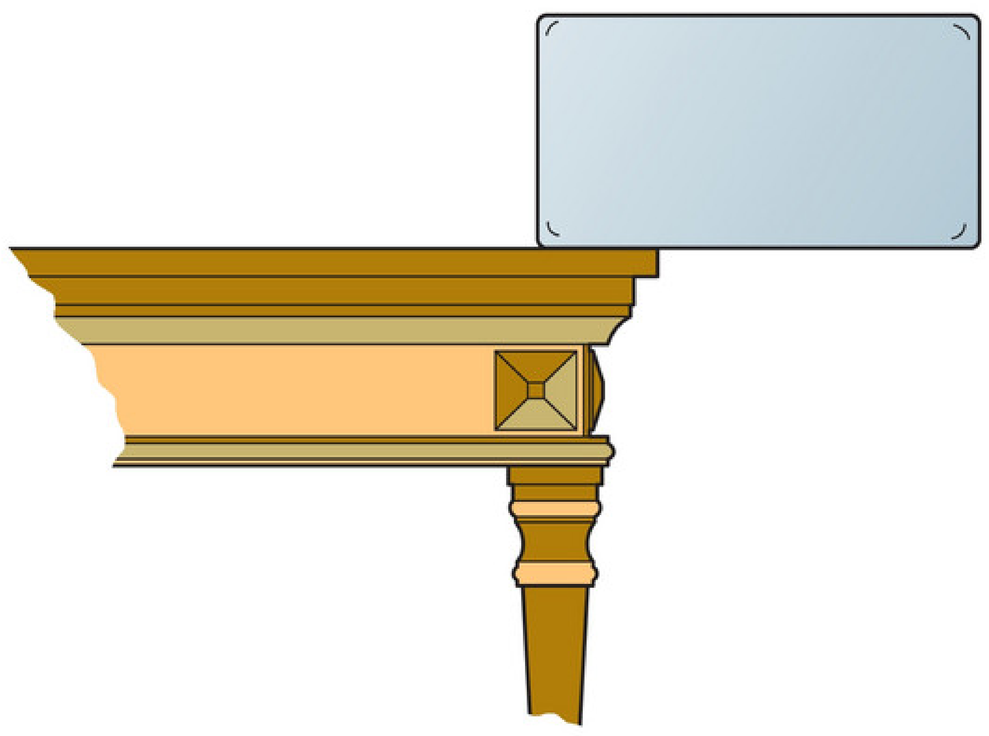


figure 13 A box on a table.

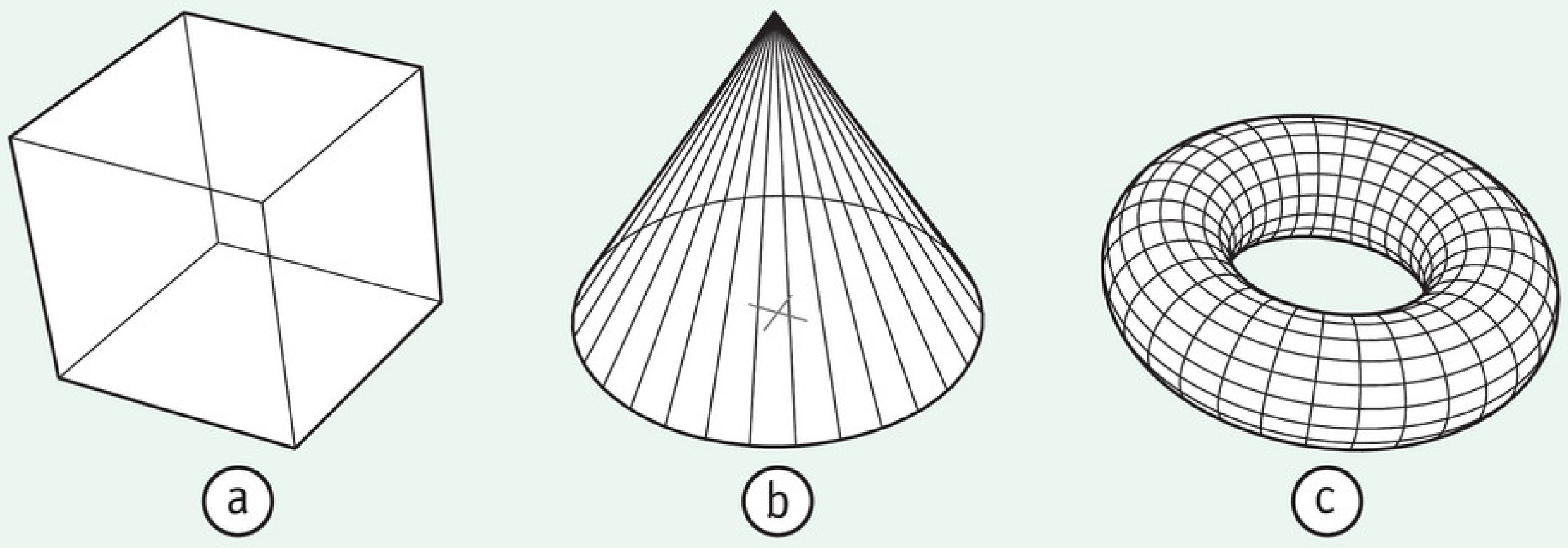
Test what you know with *Test yourself*.

PLUS DETERMINING THE CENTRE OF GRAVITY

10

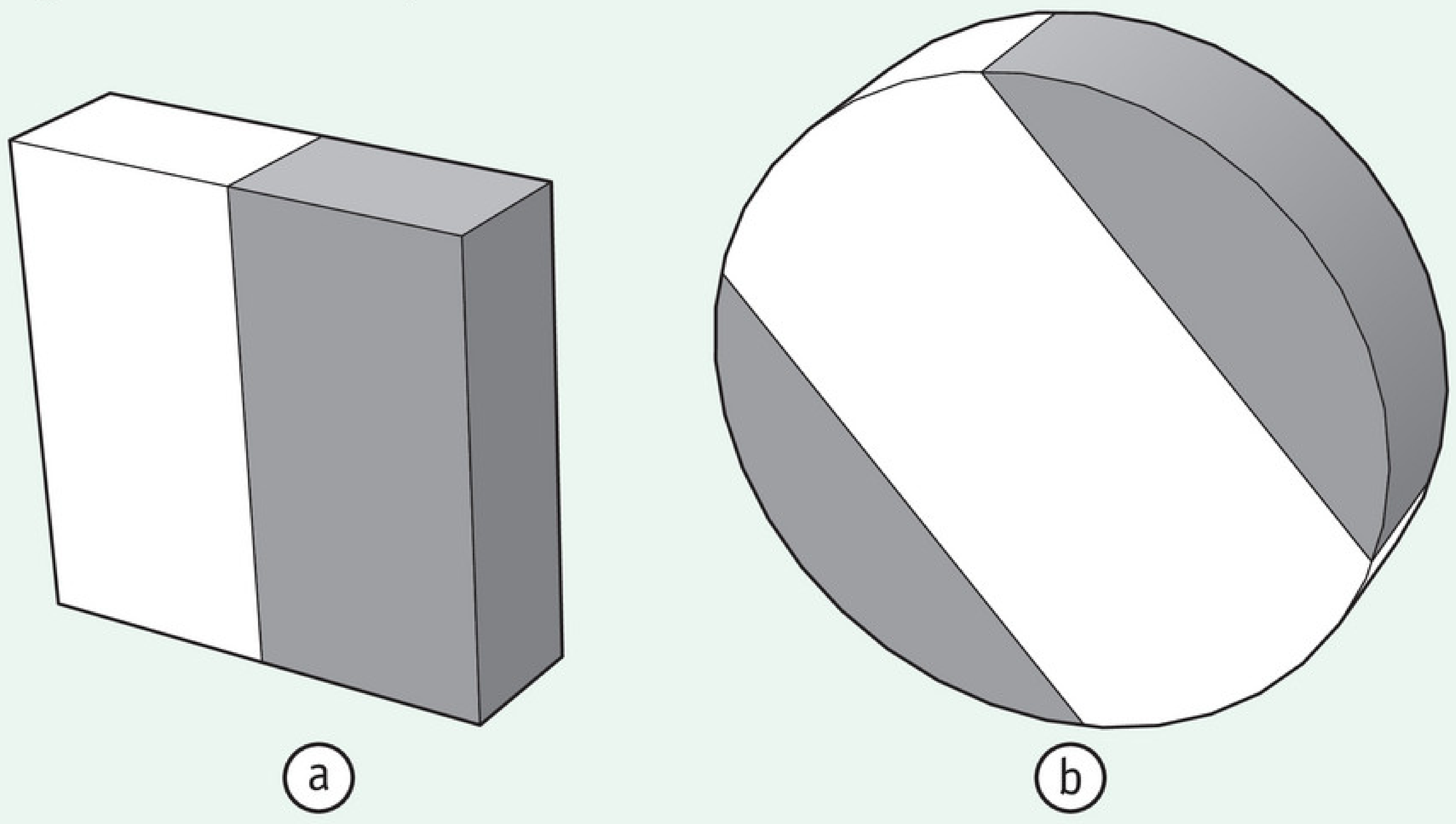
a Figure 14 shows you three objects made from the same material.
For each of the objects, place a C to indicate (roughly) where the centre of gravity is.

figure 14 The centres of gravity of three objects.



b The objects in figure 15 are made partly of iron (the darker part) and partly of aluminium (the paler part).
Indicate the centre of gravity of each object.

figure 15 Two objects made of iron and aluminium.



11

Fatma is searching the Internet for information about distant solar systems. In the simplest model for such a system, a planet orbits a stationary star. However, in practice both bodies orbit a common centre of gravity. Figure 16 shows a simplified diagram of this.

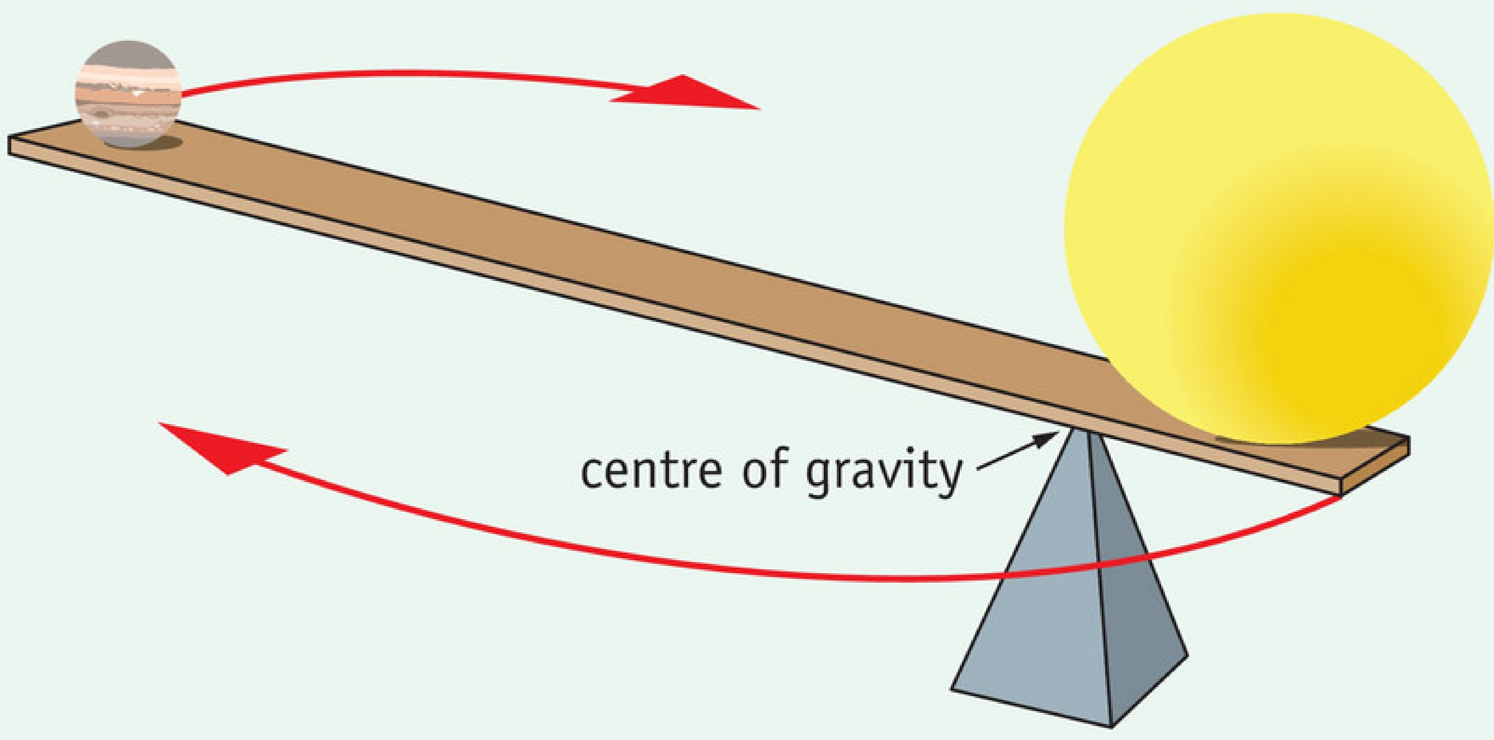


figure 16 A planet and a star orbit around a common centre of gravity.

a Using figure 16, explain why the common centre of gravity is closer to the star than the planet.

b It is not possible to see planets outside our own solar system with a telescope but the stars they orbit can often be seen.
Using figure 16, explain how astronomers can discover a planet orbiting a star.

c Suppose that the planet in figure 16 was replaced by a second star with precisely the same mass as the star in the figure.
Describe the motion of the two stars.

2 More than one force

LEARNING OBJECTIVES

2.2.1 You can describe two situations in which a force is in equilibrium with gravity.
2.2.2 You can work out how big a force must be to achieve equilibrium.
2.2.3 You can measure the stretch of a spring on which a force is exerted.
2.2.4 You can use measurement data to determine the spring constant of a spring.
2.2.5 You can calculate the resultant if there are two or more forces along the same line.
2.2.6 You can use the parallelogram method to calculate the resultant if the forces are at an angle to each other.
PLUS 2.2.7 You can calculate the resultant if the forces are perpendicular to one another.

In an arm-wrestling match, the two opponents can hold one another in balance for a long time. Even though they are pushing as hard as they can, their arms hardly move at all. As long as the force to the left is the same as the force to the right, nothing changes.

TWO FORCES IN EQUILIBRIUM

Figure 1 shows you a bag of potatoes hanging on a dynamometer. There are two forces acting on the bag: the force of gravity F_g and the resistance of the spring F_r. Gravity acts downwards and the resistance of the spring acts upwards.

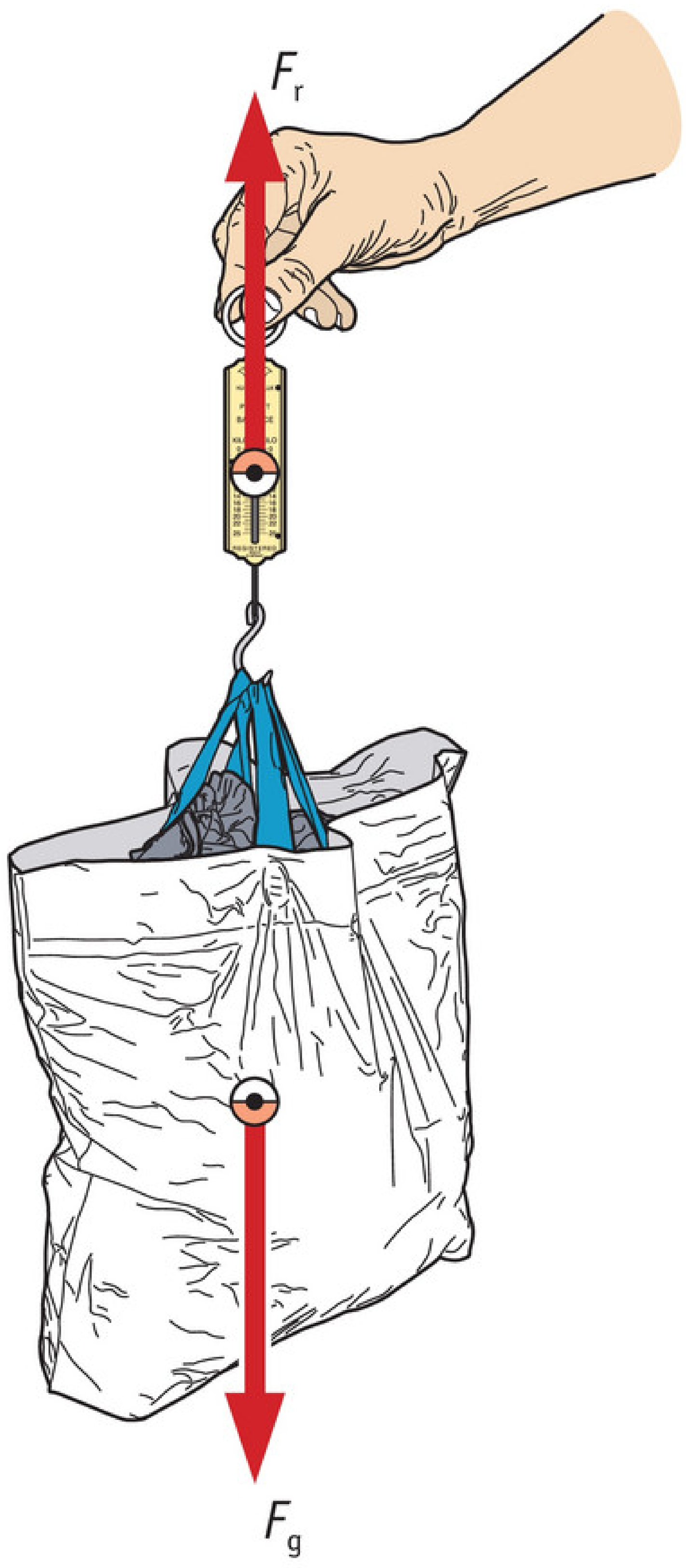


figure 1 Forces of gravity and resistance.

The forces in this situation are in equilibrium, which means that they are balancing each other out. Both are pulling equally hard on the bag, but in opposite directions. And so nothing happens: the bag doesn't move upwards and it doesn't move downwards either. The forces due to the spring and due to gravity balance each other out.

If you hang an object on a spring, it will not immediately be in equilibrium. You can also see that: the object moves downwards and the spring stretches further. As it does so, the spring's resistance increases. That continues until the resistance equals the force due to gravity. At that moment, the system is balanced.

Figure 2 shows you another example of two forces that are in equilibrium. If the tabletop wasn't there, the fruit bowl would fall. That doesn't happen because the fruit bowl pushes the tabletop down a tiny bit. As a result, the tabletop exerts a force upwards on the fruit bowl, perpendicular to the tabletop. This is the **normal force** F_n. The normal force balances the force of gravity so that the fruit bowl stays in place.

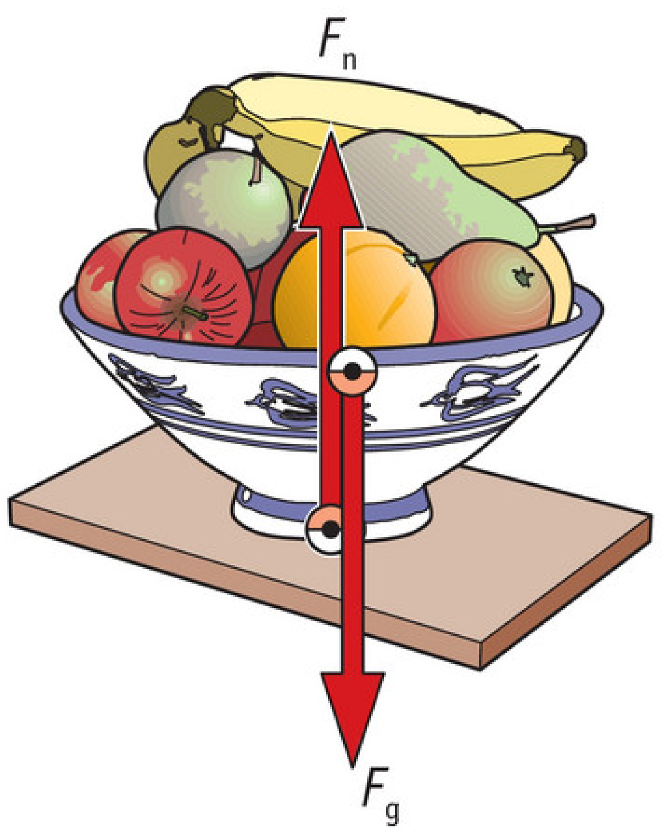


figure 2 The force of gravity and the normal force.

FORCE AND EXTENSION

EXP. 1+2

Figure 3 illustrates how you can determine the relationship between the force on a spring and its **extension**. You keep hanging weights on the spring and determine the extension each time. The extension is the number of centimetres that the length of the spring increases by compared with the **zero position**. As you can see in figure 3, the zero position is the length at the start of the experiment before any weights are attached to the spring.

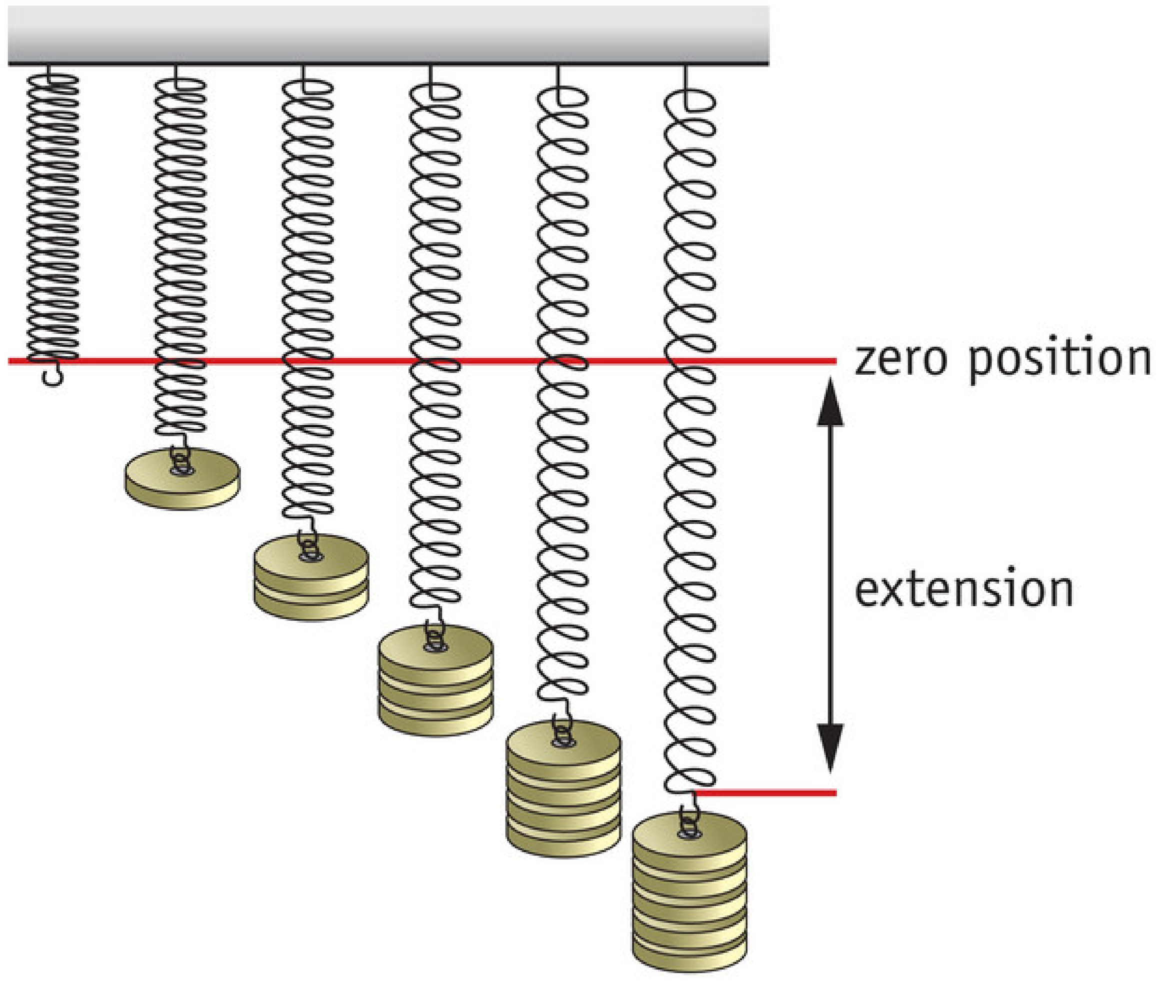


figure 3 Experiment with a coil spring.

You can do this experiment to show that the extension is **directly proportional** to the force:

- If the force is 2× greater, the extension is also 2× greater.
- If the force is 3× greater, the extension is also 3× greater.
- and so forth.

If you plot the measurements as a graph, the result is a straight line through the origin (figure 4).

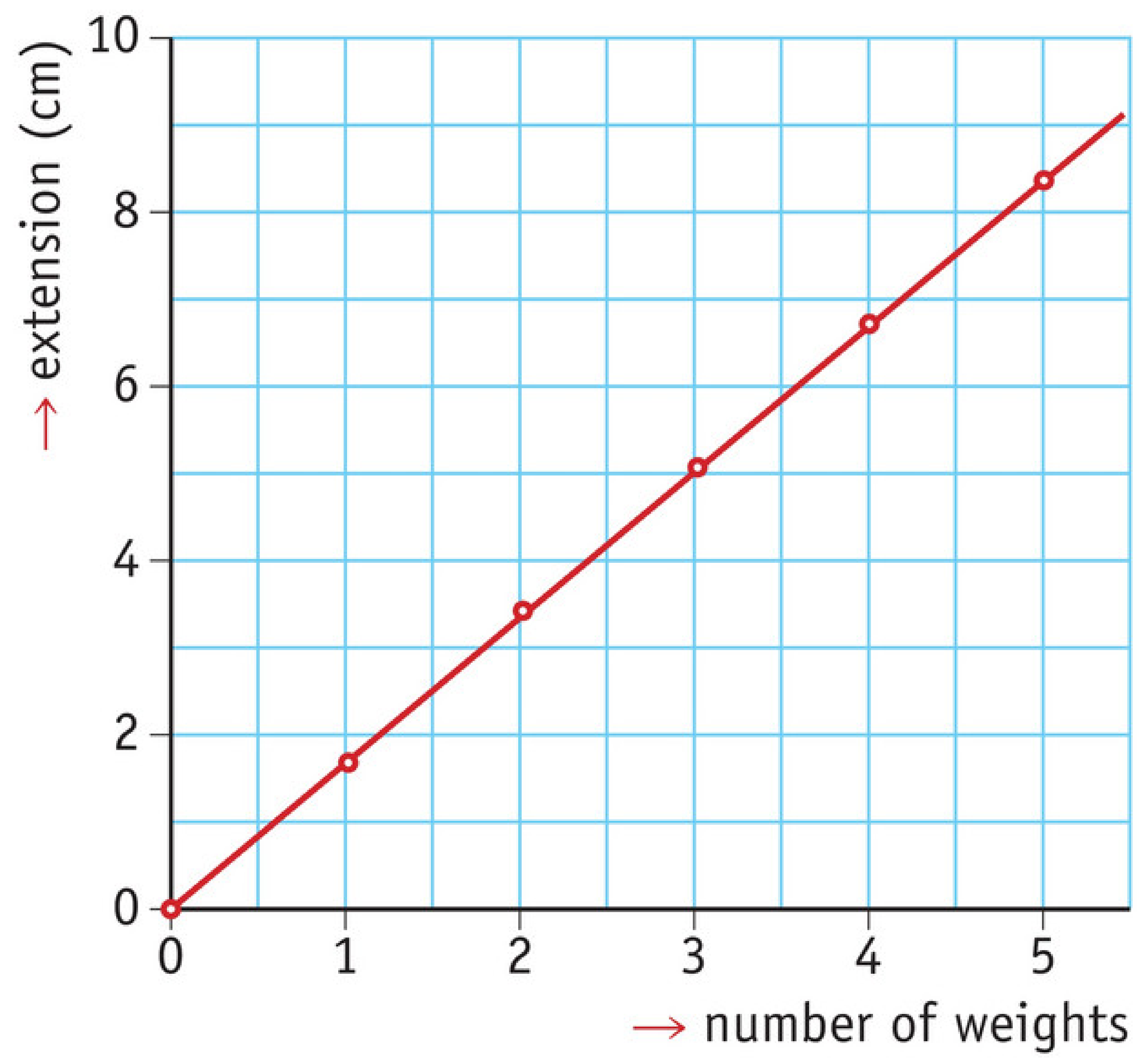


figure 4 The graph of the experiment with the coil spring.

Because the extension of a spring is proportional to the force, you always get the same value if you divide the force by the corresponding extension. This constant value *C* is called the **spring constant**. In symbols:

$$C = \frac{F}{x}$$

where:
- *C* is the spring constant in newtons per centimetre (N/cm);
- *F* is the force that pulls on the spring in newtons (N);
- *x* is the extension of the spring in centimetres (cm).

The spring constant indicates how far a spring extends if a force is exerted on it. A spring with $C = 200$ N/cm, for example, is much stiffer than a spring with $C = 2$ N/cm.

EXAMPLE EXERCISE 1

A spring is 23.2 cm long when nothing is hanging from it and 31.8 cm long when a weight of 250 g is hanging from it.
Use this data to calculate the spring constant of this spring.

given $x = 31.8 - 23.2 = 8.6$ cm
$m = 250$ g $= 0.25$ kg

required $C = ?$

working $F_g = m \cdot g = 0.25 \times 9.8 = 2.45$ N
$$C = \frac{F}{x} = \frac{2.45}{8.6} = 0.28 \text{ N/cm}$$
A force of 0.28 N is therefore needed to extend the spring by 1.0 cm.

DETERMINING THE RESULTANT

When forces are in equilibrium, they cancel each other out: it seems as if no forces are acting on the object at all. In that case, you can say that the **resultant** force F_{res} on the object is 0 N. The resultant is the sum of all the forces added together. The resultant is also sometimes called e.g. the resultant force, net force or total force.

If the forces are acting along the same line, you can calculate the resultant by adding the forces together. When you do that, you do have to allow for the directions that the forces are acting in. You therefore have to count forces in one direction as positive numbers and forces in the opposite direction as negative numbers (figure 5). You can decide for yourself which direction you call positive.

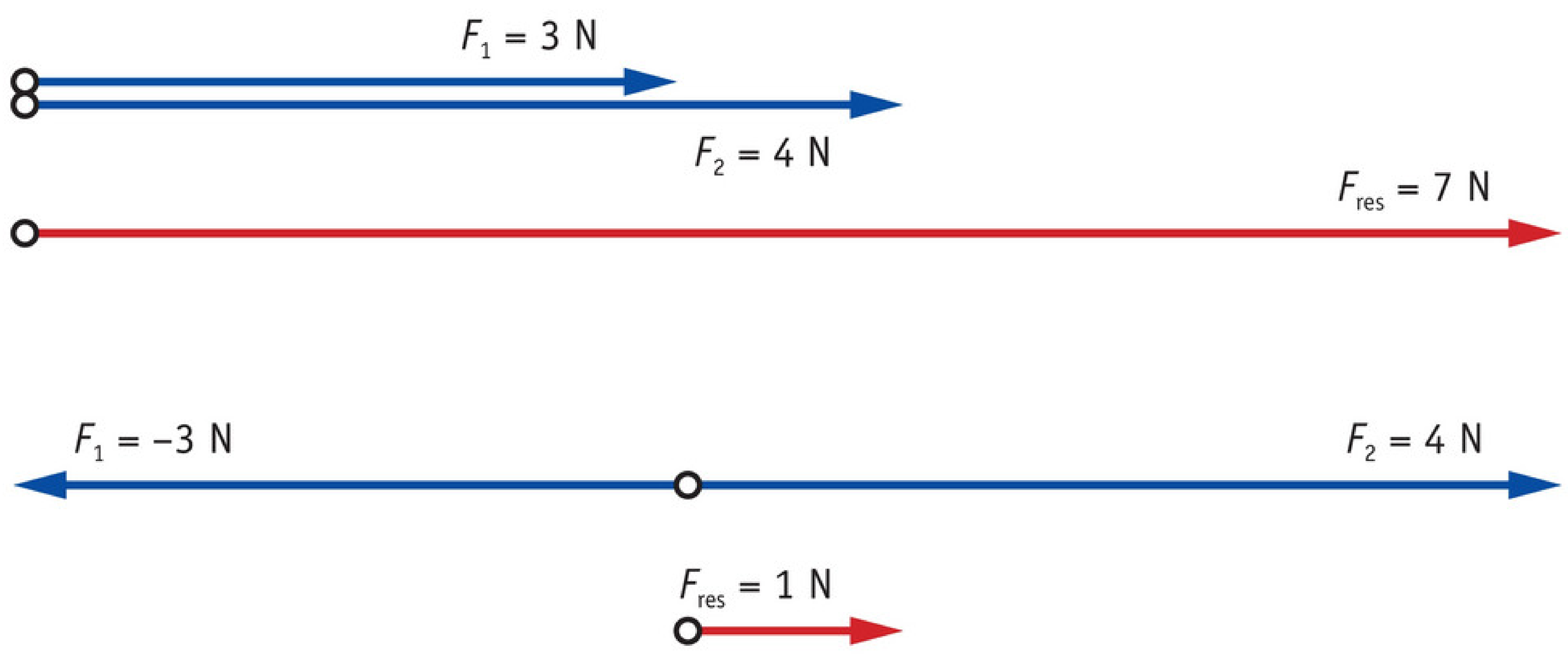


figure 5 Adding up forces.

EXAMPLE EXERCISE 2

Joe is having an arm-wrestling match with his dad (figure 6). To make it fairer, his sister is helping him. Dad pushes to the right, exerting a force of 189 N. Joe's push exerts a force of 93 N to the left and his sister's push is 98 N.
Work out which team is winning.

given F_1 = 189 N; F_2 = −93 N; F_3 = −98 N

required F_{res} = ?

working $F_{res} = F_1 + F_2 + F_3$
$= 189 - 93 - 98 = -2$ N

The resultant is 2 N in favour of Joe and his sister.

figure 6 An arm-wrestling contest.

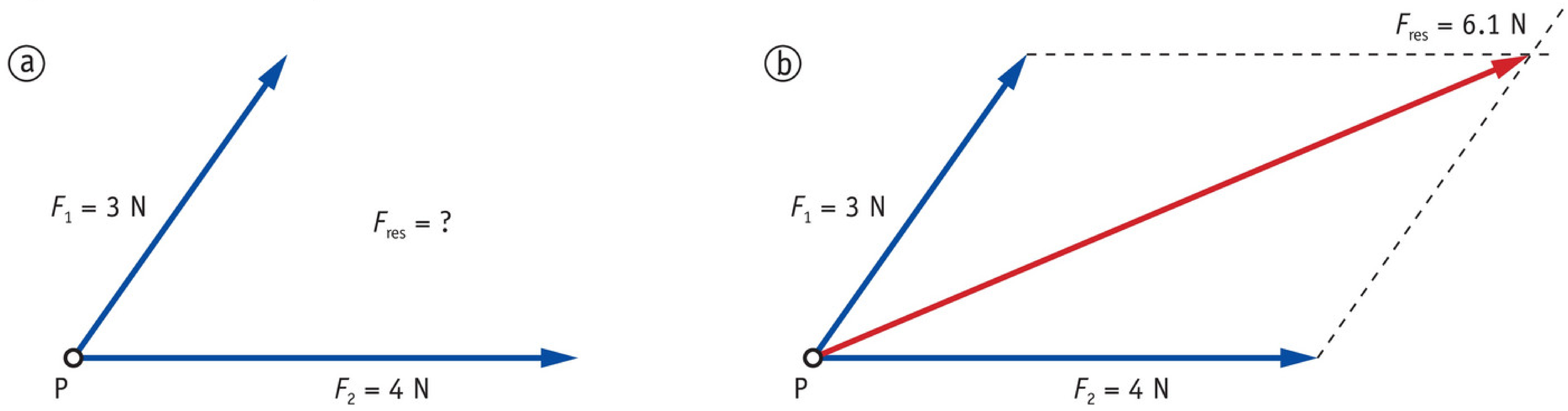
ADDING FORCES TOGETHER

Figure 7a shows you two forces that are acting in different directions. In a case like this, there is no simple way of calculating the resultant. This is because forces are vectors. The direction matters, as well as the magnitude. So you can't simply add them up.

To find the resultant in this situation, you use the **parallelogram method** (or "parallelogram of forces"). It works like this:

1. Choose a suitable scale of forces so that the arrows aren't too long or too short.
2. Draw in the two forces at the correct scale and at the correct angles.
3. Complete the parallelogram with two dotted lines as shown in figure 7b.
4. Draw the resultant as an arrow from the origin P to the opposite corner.
5. Measure the length of the arrow. Use the scale of the forces to determine the magnitude of the resultant.
6. Determine the direction of the resultant by measuring the angle in figure 7b.

figure 7 This is how you determine the resultant of two forces.



PLUS PERPENDICULAR FORCES

Figure 8 shows you a construction for the resultant when two forces are perpendicular to each other. As with the parallelogram of forces method, you can now measure F_{res}. However, it's a lot more accurate to calculate the resultant. You can do that using Pythagoras' theorem. The following applies:

$$F_{res}^2 = F_1^2 + F_2^2$$

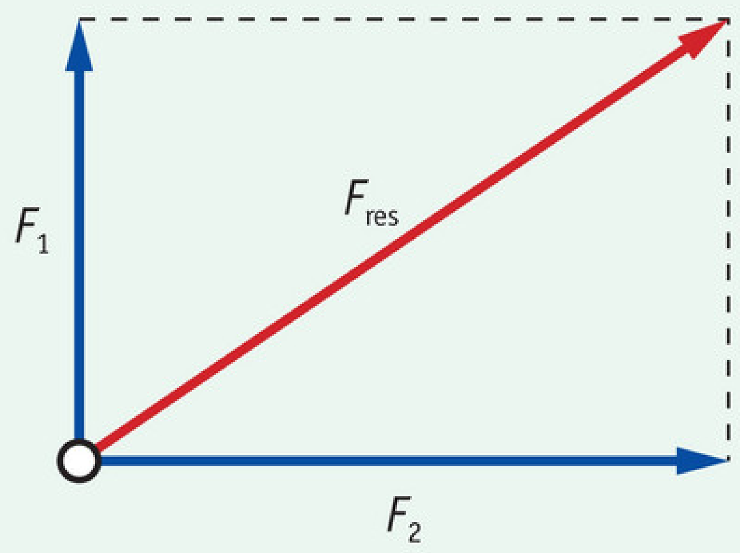


figure 8 This is how you determine the resultant of two perpendicular forces.

EXAMPLE EXERCISE 3

In figure 8, F_1 = 12 N and F_2 = 18 N.
Calculate the resultant.

given F_1 = 12 N and F_2 = 18 N

required F_{res} = ?

working
$$F_{res}^2 = F_1^2 + F_2^2$$
$$F_{res}^2 = 12^2 + 18^2 = 144 + 324 = 468$$
$$F_{res} = \sqrt{468} = 22 \text{ N}$$

Practice the concepts using the *Flash cards*.

COURSE MATERIAL

1 Answer the following questions.

a Which three types of forces are indicated by the symbols F_n, F_r and F_g?
b What two forces are acting on a laptop that is on a desk?
c What two measurements do you need to determine the extension of a spring?
d What formula can you use to calculate the spring constant C of a helical spring?

IN PRACTICE

2 A mountaineer is taking a breather while abseiling (figure 9).

a What two forces are acting on the mountaineer?
b In the figure, show:
- the points of application of the two forces;
- the directions the two forces are acting in;
- the lines along which the forces are acting.

figure 9 A mountaineer.

3 William is doing the experiment that has been drawn in figure 10.

a Some of the results he has measured are shown in table 1.
Complete the rest of the table.

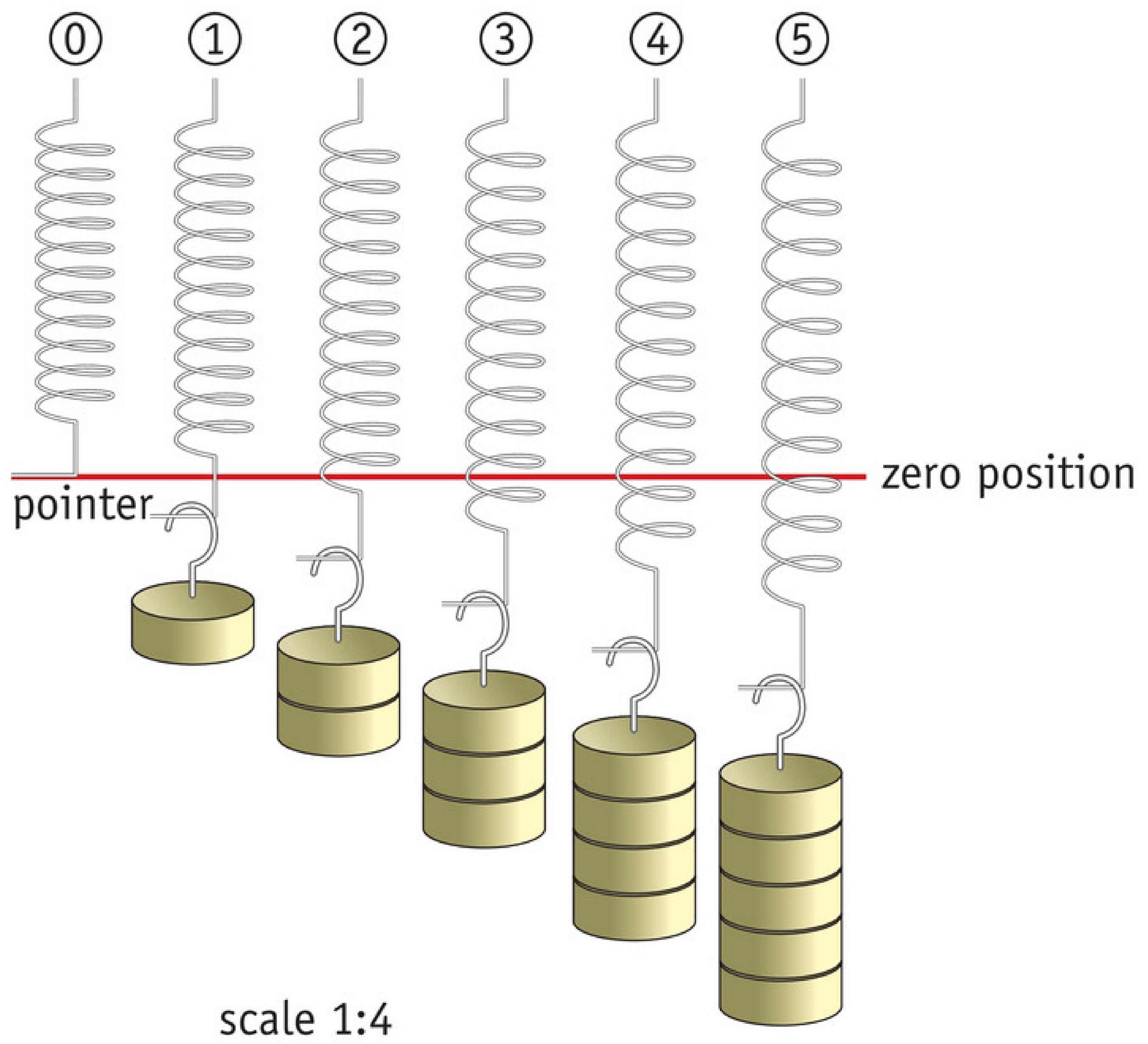


figure 10 The spring keeps stretching further.

table 1 William's measurements.

number of weights	force on the spring (N)	extension (cm)
0	0	0
1	0.15	1.8
2	0.30	

b See the skills section on *Working with tables and graphs*.
Draw the graph for this experiment in the diagram in figure 11.

c Use the graph to determine:
- how far the spring would be stretched by a force of 0.5 N;
- how far the spring would be stretched by a force of 0.8 N.

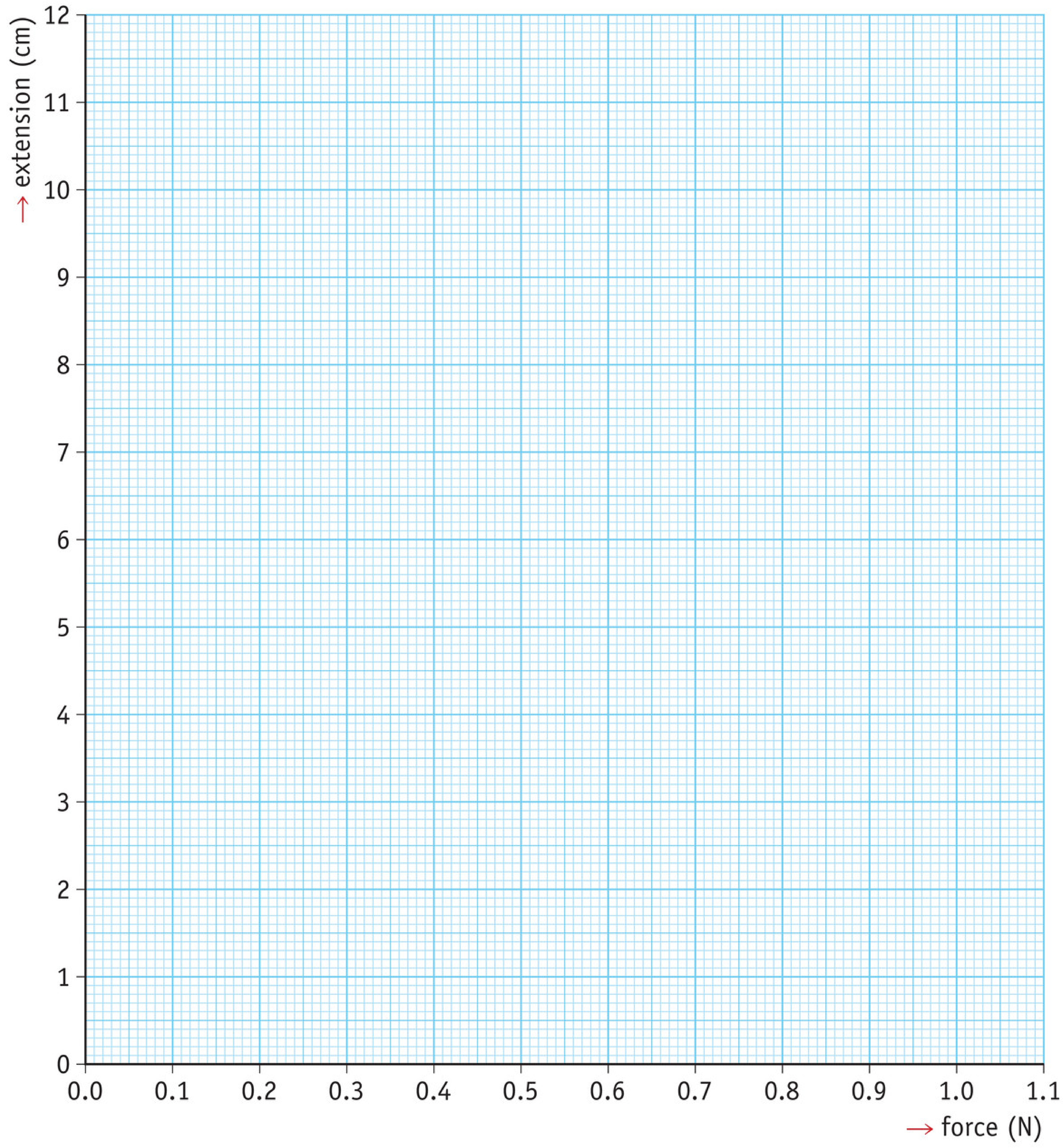


figure 11 The relationship between force and extension.

4 Figure 12 shows three dynamometers of equal length: red (range 0 to 2 N), brown (0 to 5 N) and green (0 to 10 N). The distance between the zero point and the end point of the scale for each dynamometer is 8.4 cm.

a How can you see from this data which dynamometer has the stiffest spring?

b See the skills section on *Working with formulae*.
Calculate the spring constant of the spring in the red dynamometer.

c Without using a formula, work out what the spring constants in the other dynamometers must be.

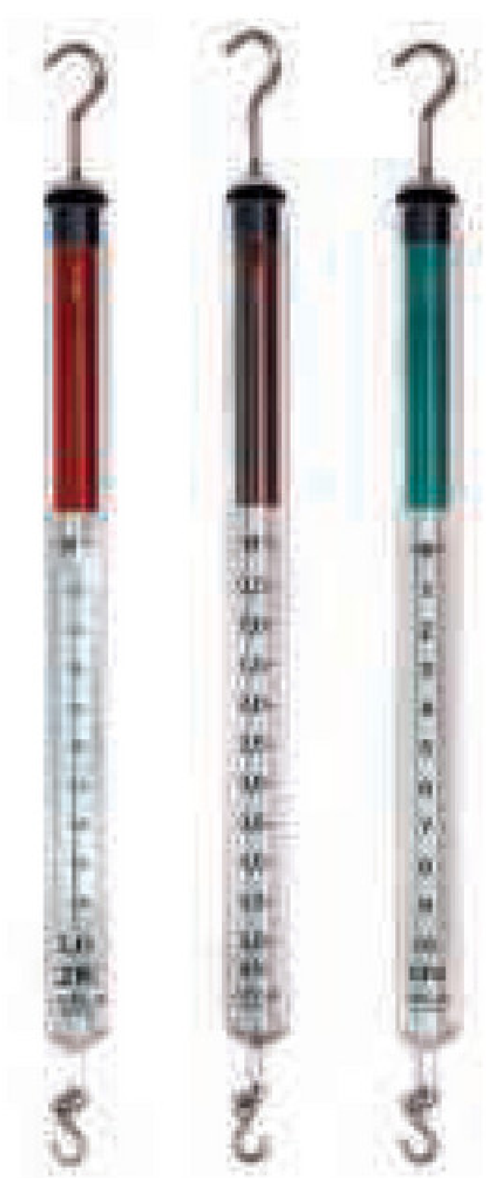


figure 12 Three dynamometers.

★ 5

Ellen is doing an experiment with a helical spring (C = 0.35 N/cm). First, she measures the length of the spring with nothing hanging on it: 22 cm. Then she hangs a block of mass 250 g on the spring.
Calculate how long the spring will get. Show all your calculation steps clearly.

If you need more practice with *Calculating spring constants*, go to the *Skills Trainer*.

★ 6

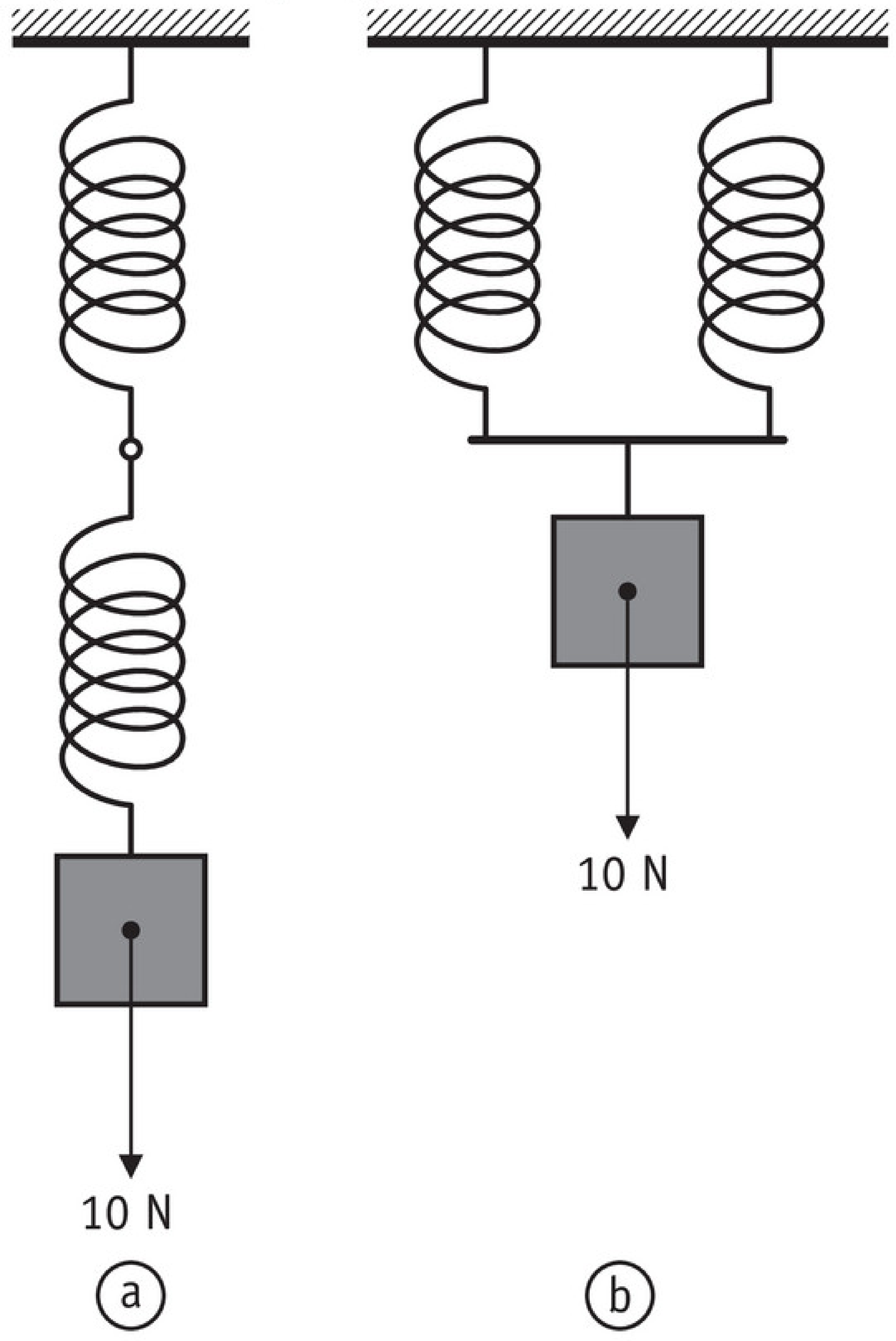
Joshua suspends two identical helical springs one from the other and hangs a weight of 10 N on them (figure 13a). You may assume that the mass of the springs is negligible.

a Give the size of the force exerted on each of the springs.

b The spring constant of each spring is 6.0 N/cm.
What is the spring constant of this combination of the two springs? Explain how you got your answer.

c Joshua now suspends the springs in parallel (figure 13b).
What is the spring constant of the combination now?
Explain how you got your answer.

figure 13 Springs in series and in parallel.



7

Figure 14 shows you how you can make a paperclip on a piece of string 'float' using a magnet.
There are three forces acting on the paperclip.

a Which two forces are acting downwards?

b Which force on the paperclip is acting upwards?

c Which of the three forces is greatest? How can you tell that?

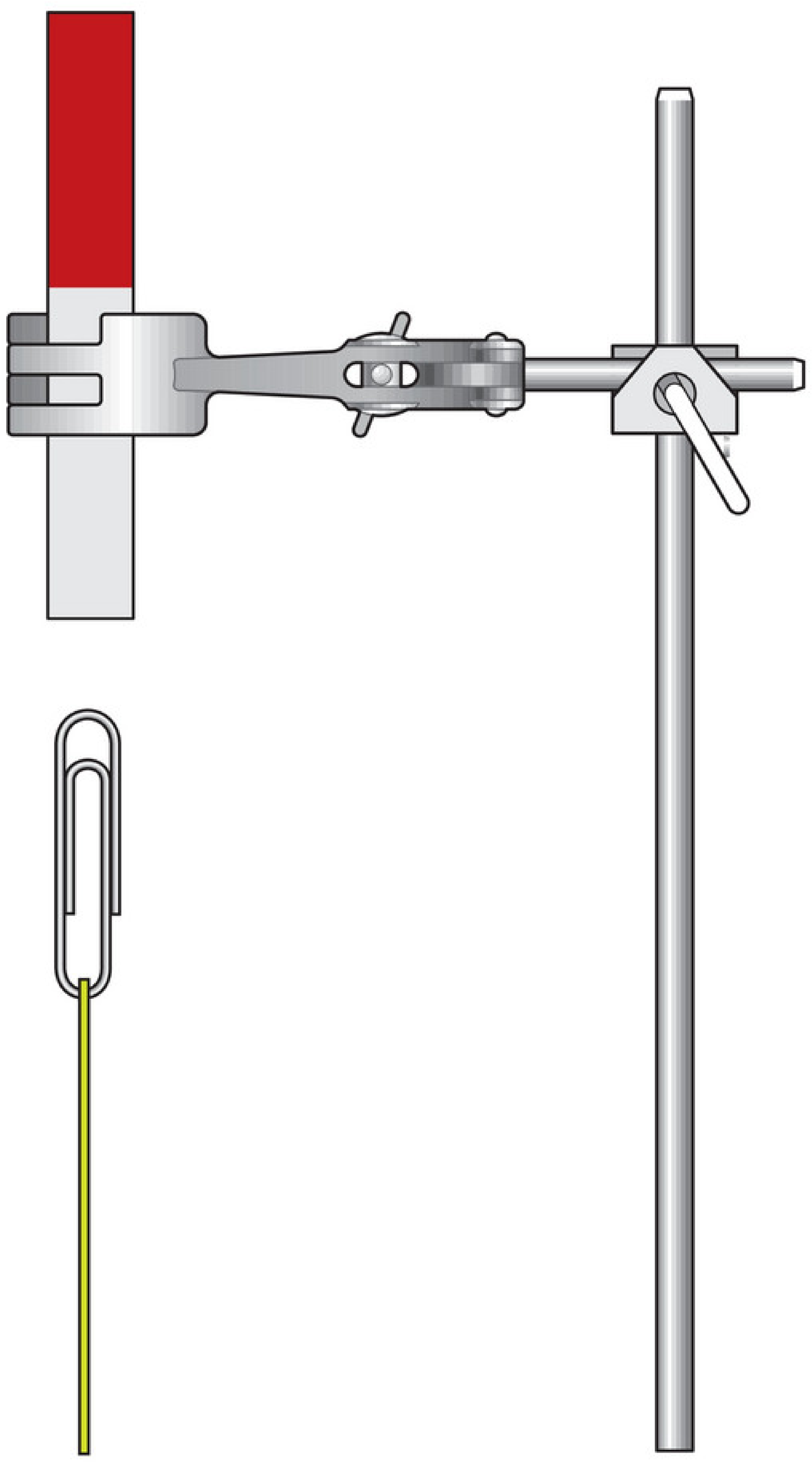


figure 14 The floating paperclip.

8 Figure 15 shows five drawings labelled (a) to (e) in which two forces F_1 and F_2 are acting on the same point.

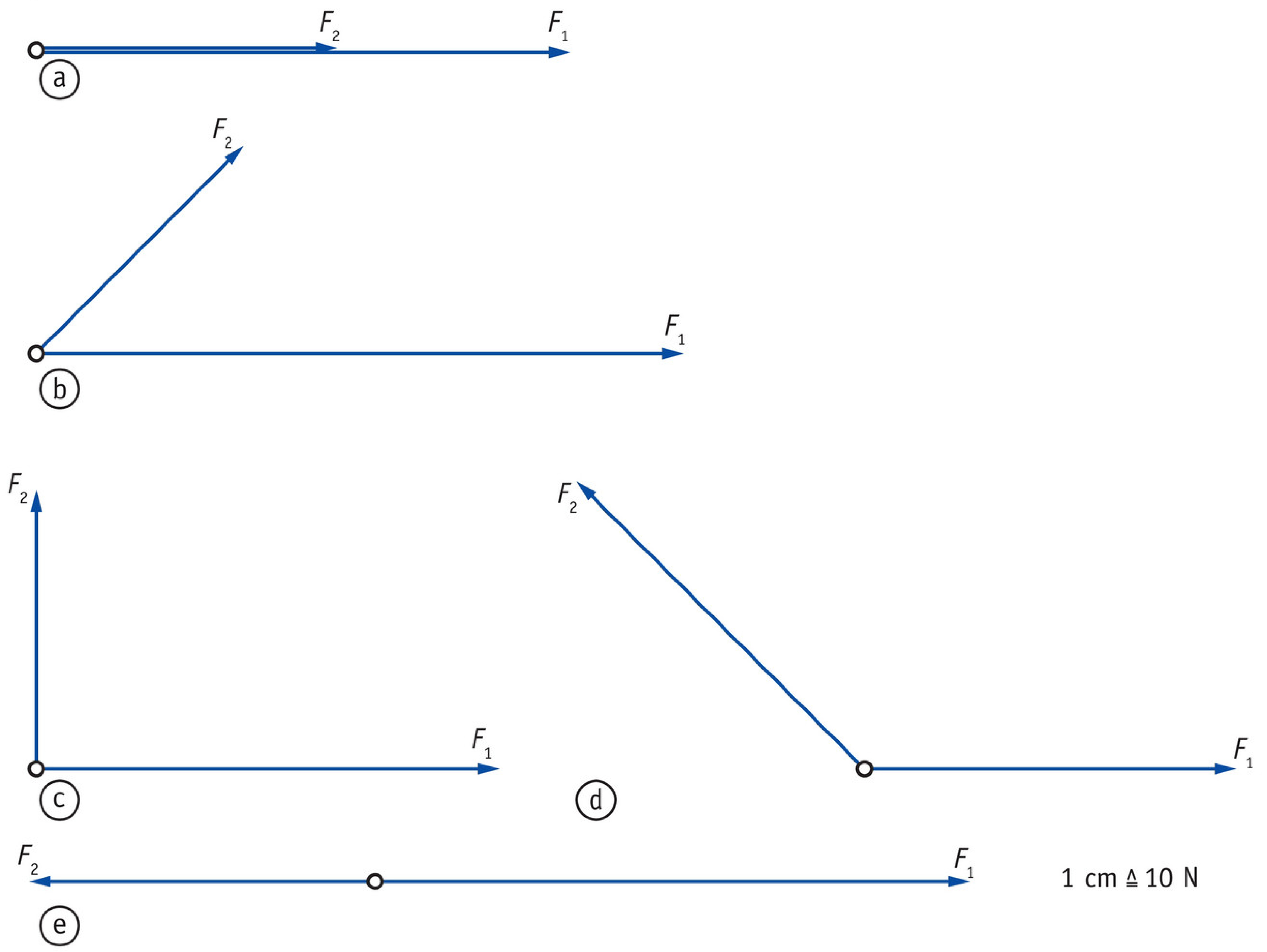
a For each of the five drawings, add in the resultant of F_1 and F_2.

b Complete the rest of table 2.

table 2 What are the resultants?

drawing	length of the resultant (cm)	magnitude of the resultant (N)
a		
b		
c		
d		
e		

figure 15 Five situations with two forces.



9 Figure 16 is a sketch showing how tugboats A and B are pulling a cargo ship forwards. Each tug is exerting a force of 600 kN on the ship.

- **a** Draw these forces in figure 16. Calculate the force scale using the figure.
- **b** Draw in the resultant of these two forces.
- **c** Determine the magnitude of the resultant.

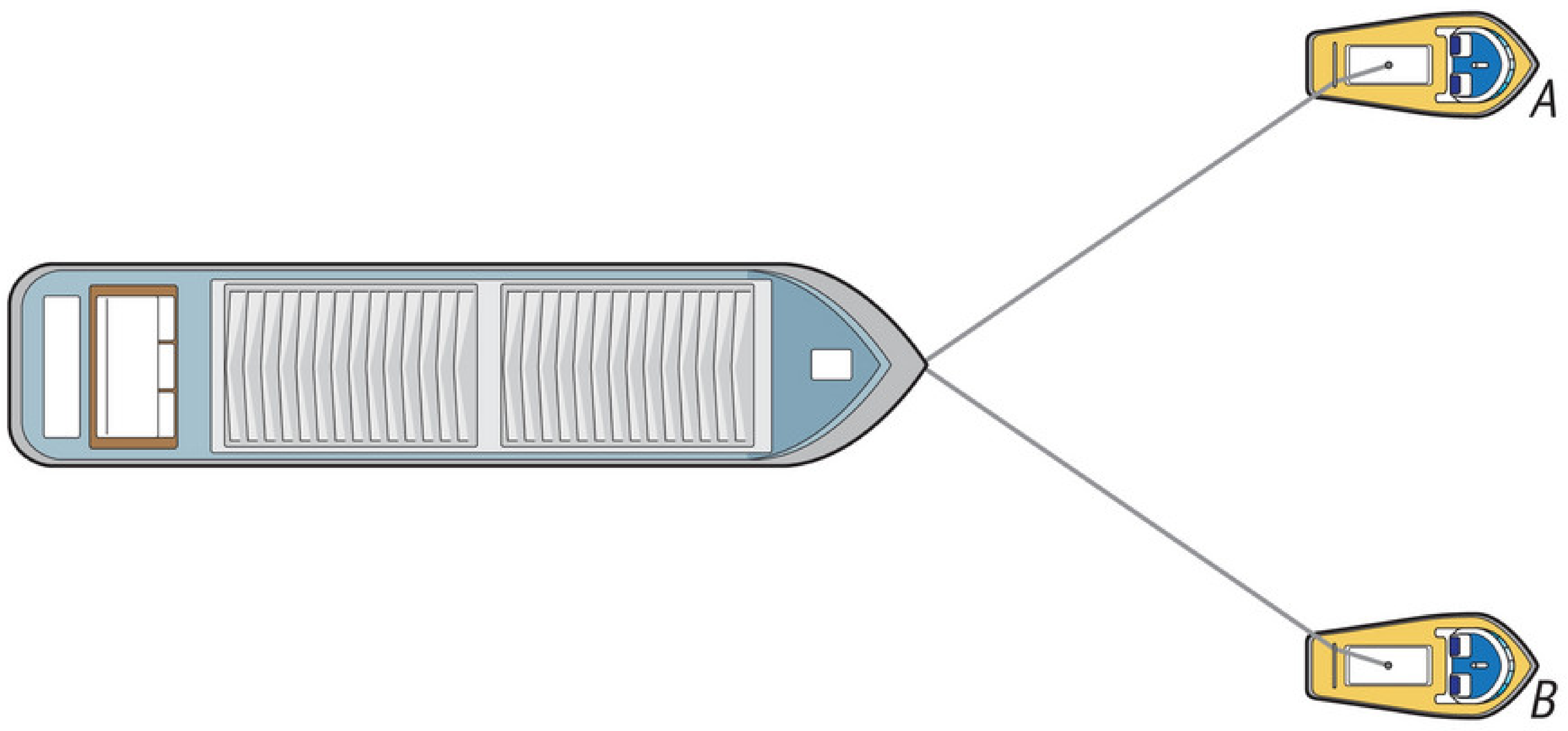


figure 16 Determining the resultant.

Test what you know with *Test yourself*.

PLUS PERPENDICULAR FORCES

10 Two forces $F_1 = 3$ N and $F_2 = 4$ N are acting on the same object. F_1 is to the left and F_2 is downwards.

- **a** Draw these forces and the resultant. Use a scale of 1 cm $\triangleq$ 1N.

- **b** Determine the resultant in the drawing.
- **c** Calculate the resultant.

11 A steel cable runs over a brown and yellow pulley (figure 17). Assume that the cables make an angle of precisely 90°. The tensile force in each cable is 50 kN.

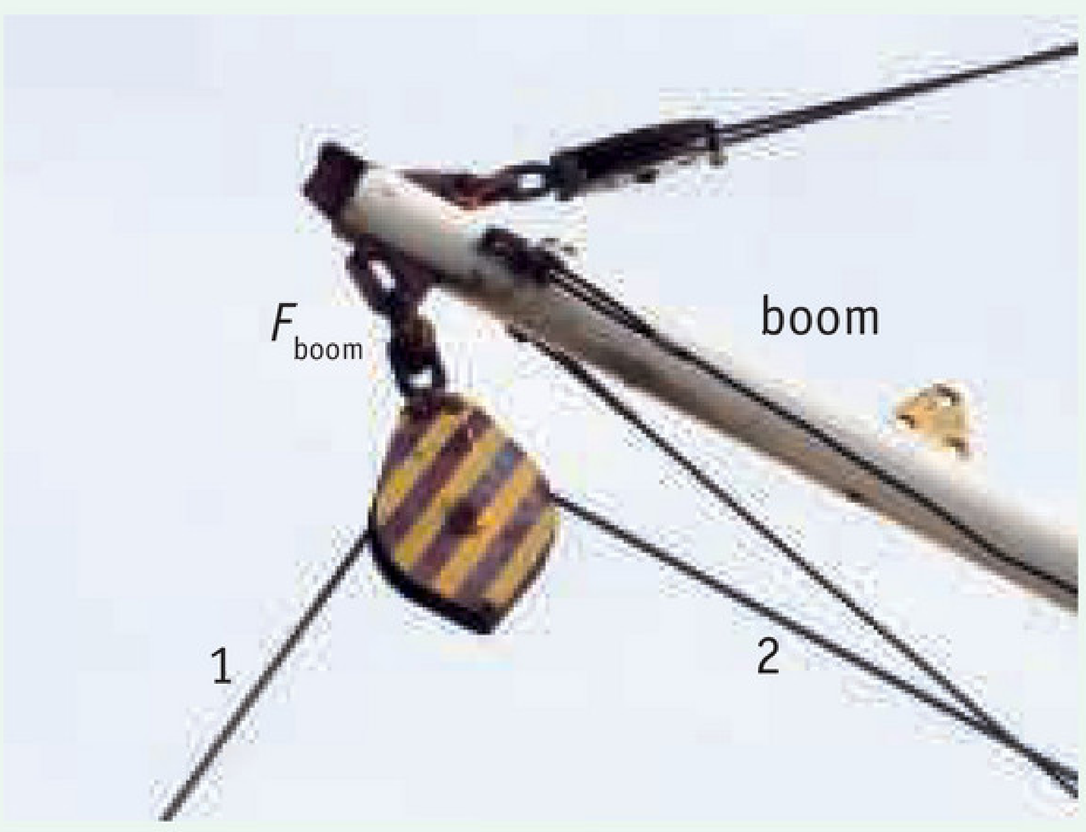


figure 17 A brown-and-yellow striped pulley on the boom of a crane.

a Draw the tensile forces F_1 and F_2 and their resultant. Use a scale of 1 cm ≙ 10 kN.

The length of the resultant is .... cm.

b Calculate the size of the resultant F_{res}.

c What is the force F_{boom} that the boom exerts on the pulley?

12 Sam is walking his two dogs, his pug and his chihuahua (figure 18). The pug sees a friend to the north and pulls on the lead with 28 N. At the same time, the chihuahua sees something interesting in the woods to the east. The net effect is to pull Sam diagonally forwards. The two dogs combined exert a force of 30 N on him.

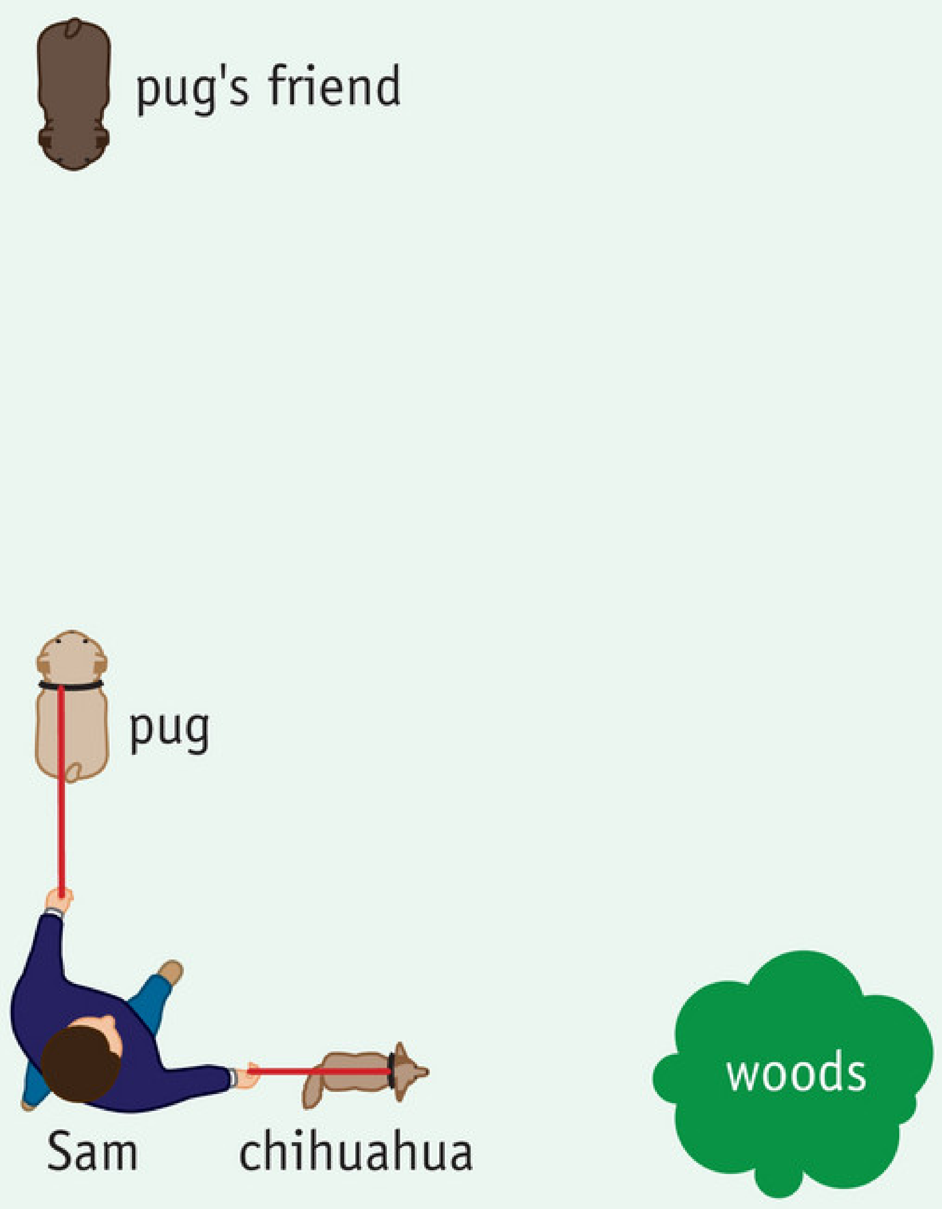


figure 18 Sam is walking his chihuahua and his pug.

a Draw the forces acting on Sam: F_p from the pug, F_c from the chihuahua and the resultant F_{res}.

b Calculate the force that the chihuahua is exerting on the lead.

3 Driving forces and resisting forces

LEARNING OBJECTIVES

2.3.1 You can explain how motion in space differs from motion on the Earth.
2.3.2 You can state how three kinds of resistance arise and how you can reduce them.
2.3.3 You can explain what Newton's First Law is and the thinking behind it.
2.3.4 You can describe how an object moves if the resultant is equal to 0 N.
2.3.5 You can describe how an object moves if the resultant is not equal to 0 N (four possibilities).
PLUS 2.3.6 You can calculate the air resistance to a moving object.

The rockets that are used to launch spacecraft use up hundreds of tons of fuel. That gives them enormous thrust. But after a few minutes, the fuel has been used up and the force pushing forward has gone. The spacecraft then detaches itself and travels further.

A JOURNEY WITHOUT END

Figure 1 shows a picture of Voyager 2. This unmanned spacecraft was launched in 1977. In the years that followed, it visited all the giant planets in the solar system. Since that time, it has been moving further and further away from the Sun. Its speed is big enough for it to leave the solar system altogether. In the end, Voyager 2 will disappear into deep space on a journey without end.

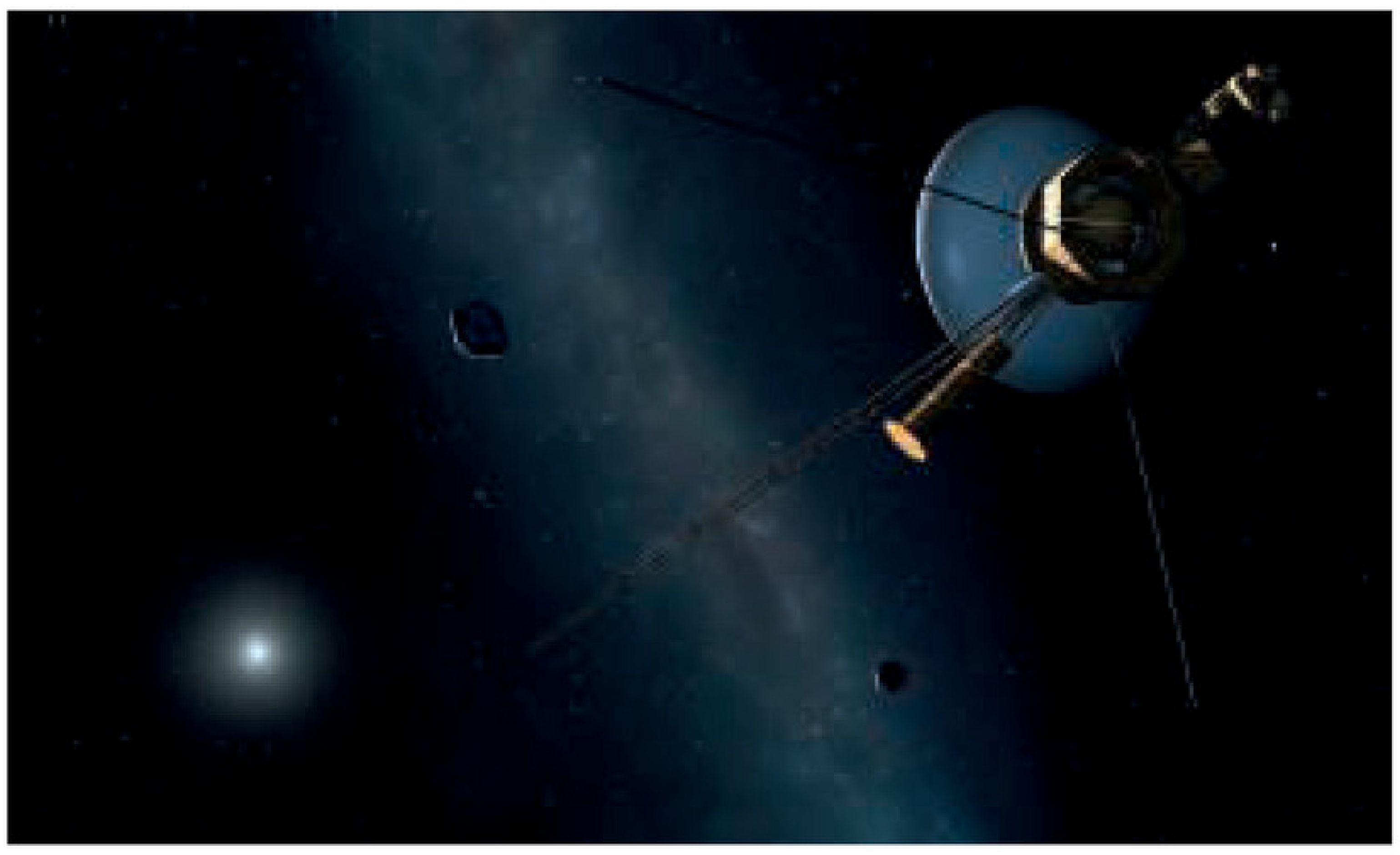


figure 1 Voyager 2 at the edge of the solar system (*artist's impression*).

In the vacuum of space, a spacecraft is not slowed down by air or any other material. There are no molecules to be pushed aside before it can move further. If the right direction and speed are chosen when the spacecraft is launched, it keeps moving of its own accord after that. Voyager 2 has travelled billions of kilometres in this way, as far as the edge of the solar system.

Motion on the Earth is different, as there are always **resistance forces** that act against your motion. You notice this when you are cycling, for example. You have to keep pedalling to maintain a constant speed. If you stop pedalling, you soon come to a stop. The forces of resistance have brought your bicycle to a standstill.

THREE RESISTIVE FORCES

EXP. 3

There are various kinds of resistance forces (or resistive forces):

- An object that moves through the air meets **air resistance**. That is because the object has to push the air in front of it aside. You can reduce air resistance by making the object streamlined.
- An object that slides or glides over a surface, such as a ski on snow, meets **sliding resistance** or **friction**. You can reduce friction by making the surfaces that move across one another as smooth as possible.
- An object that rolls over a surface, such as a bike wheel on a road, meets **rolling resistance**. That is because both the object that is rolling and the ground become deformed. You can reduce rolling resistance by making the ground hard and flat.

Athletes try to minimize the forces of resistance that act against their movement. When skiing down a mountain, skiers make themselves as small as possible, for example. They then do not have to push so much air aside because their **frontal cross-section** – their surface area as seen from the front – is smaller.

Race cyclists wear special clothing that makes them more streamlined (figure 2). They pump up the tyres very hard to reduce the rolling resistance. Technical improvements to their bicycles and clothing can reduce the various types of resistance a great deal, but it is impossible to eliminate these forces completely.

figure 2 A streamlined racing cyclist.

NEWTON'S FIRST LAW

There is no resistance in space. There is a vacuum there that lets moving objects pass without any hindrance. Long ago, physicists wondered how an object would move in such conditions. How would its movement behave of no forces were acting on the object or if those forces were so small that you could ignore them?

The English physicist Isaac Newton gave a convincing answer to this question. He argued as follows: if no forces are acting on the object, then there is nothing slowing the object down or making it speed up. There is also nothing making the object turn left or right from its original course. Therefore nothing at all changes in its motion. If the object was stationary, it remains stationary. If the object was already moving, it continues to move with a constant speed along a straight line.

Newton realized that his argument also applied if the resultant of all the forces is zero. In that case, the forces cancel each other out. Then too, nothing can change the size or direction of the motion. In other words,

> if the resultant of all the forces is zero (0 N), the object is either stationary or it moves along a straight line at a constant speed.

This rule is known as the **Newton's First Law**.

You can do an experiment with the air cushion track in figure 3 to test Newton's First Law. This track has a large number of holes that air is flowing out of. Because the glider is floating on a thin layer of air, the resistance forces are negligible. In the experiment shown in the illustration, the glider is given a push. It then continues to move of its own accord at an almost constant speed. That is precisely what you would expect based on Newton's First Law.

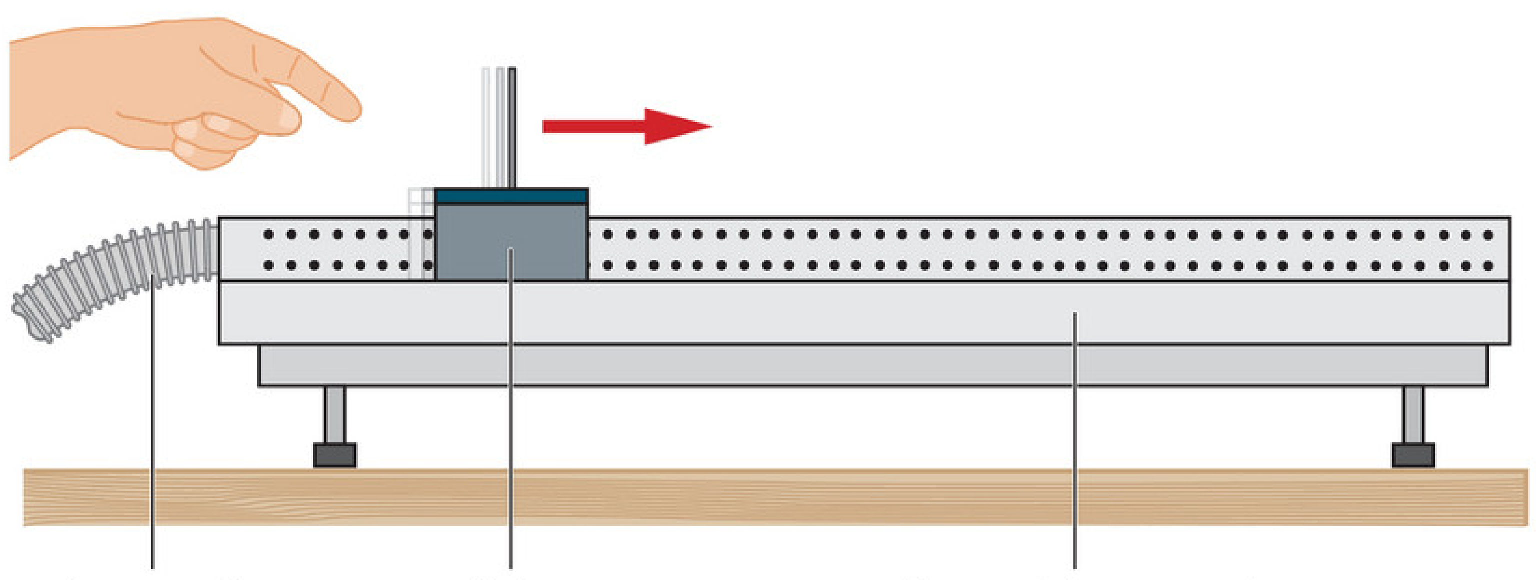


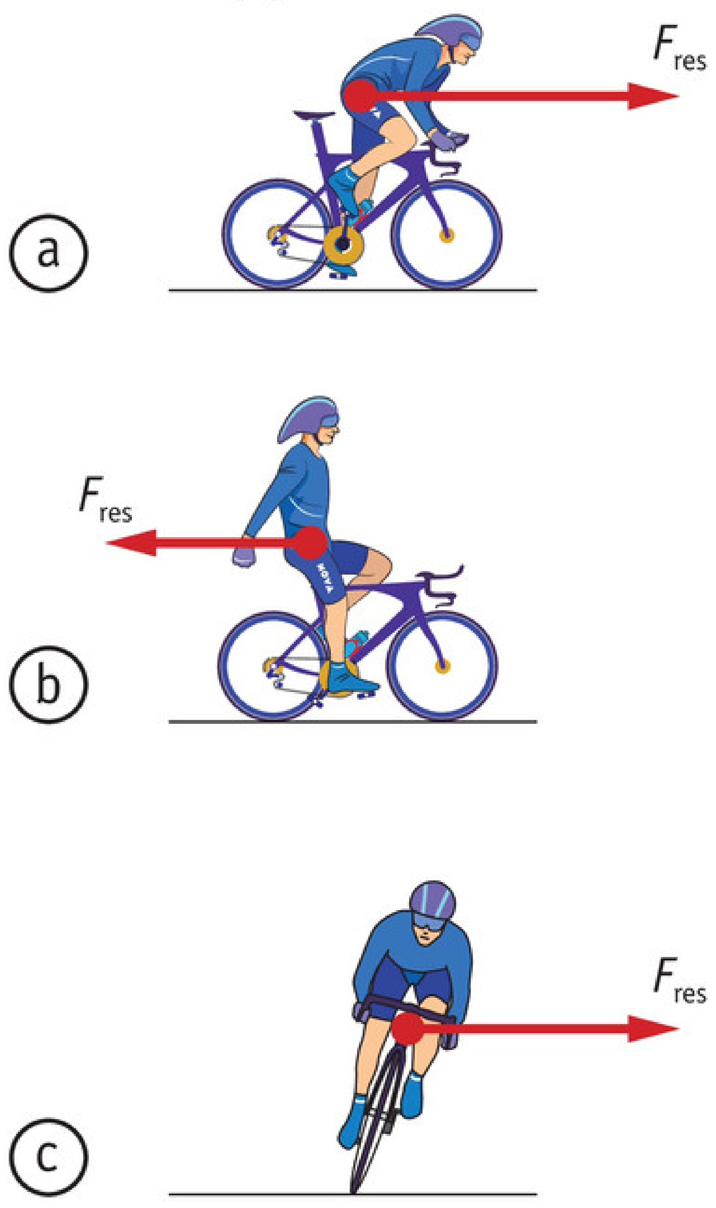
figure 3 After a little push, the glider continues to move at an almost constant speed.

CHANGE IN MOTION

In many situations, the resultant of all the forces is not 0 N, so the forces acting on the moving object do not cancel one another out. A resultant remains with a certain size and a certain direction. In that case, the object's motion changes. There are various possibilities:

1. If the direction of the resultant is the same as the direction of motion, the object's motion accelerates. You see that with a racing cyclist who pedals like mad at the start of a time trial: the speed increases (figure 4a).
2. If the direction of the resultant is opposite to the direction of motion, the object's motion decelerates. You see that when the racing cyclist relaxes after reaching the finish: the speed decreases (figure 4b).
3. If the direction of the resultant is perpendicular to the direction of motion, only the direction of motion changes. You see that with a racing cyclist who takes a bend without slowing down (figure 4c).
4. If the resultant is at an angle but not perpendicular to the direction of motion, then both the speed and the direction of motion will change. You see that when the racing cyclist takes a bend and brakes at the same time. The resultant then points diagonally backwards.

figure 4 The resultant lets the cyclist accelerate (a), decelerate (b) or change direction (c).



EXAMPLE EXERCISE 1

Julian is cycling to school at a constant speed along an exposed road, against the wind. The driving force (F_p) propelling his bike is a constant 30 N.

1 Determine the size of the combined resistive force F_r acting on his bike.

given	F_p = 30 N
required	F_r = ?
working	The resultant is 0 N because Julian is moving at a constant speed.
	Therefore: $F_r = F_p$ = 30 N

2 Suddenly the wind stops. The combined forces of resistance are now only 20 N. Determine the size of the resultant force on Julian now. Explain what effect this will have on Julian's motion.

given	F_p = 30 N
	F_r = 20 N
required	F_{res} = ?
working	The resultant is: $F_{res} = F_p - F_r$ = 30 N − 20 N = 10 N

Because the propulsive force is now greater than the combined forces of resistance, Julian's speed will increase: he accelerates.

PLUS AIR RESISTANCE

The cyclist in figure 5 faces two types of resistance: rolling resistance and air resistance (or 'drag'). When you cycle, the size of the air resistance depends on four factors:

1 The speed *v*. If you cycle fast, you have to push more air aside per second, so the air resistance is greater.
2 The density ρ of the air. If the air's density increases, the mass of air to be pushed aside is greater, so the drag (the air resistance) is also greater.
3 The frontal cross-section (*A*). Racing cyclists bend forward over their bikes to make their frontal cross-section as small as possible.
4 The degree of streamlining is indicated by the resistance coefficient or **drag coefficient** C_D. The better the streamlining, the smaller C_D is. For example, a sphere has a much smaller C_D than a cube of the same size.

These four factors are combined in the formula for air resistance:

$$F_{r,a} = \tfrac{1}{2} C_D \cdot \rho \cdot A \cdot v^2$$

where:

- $F_{r,a}$ is the size of the air resistance in newtons (N);
- C_D is the resistance coefficient, a constant that depends on how streamlined the object is (just a number, without any units);
- ρ is the density of the air in kilograms per cubic metre (kg/m^3);
- *A* is the frontal cross-section in square metres (m^2);
- *v* is the speed of the object in metres per second (m/s).

You can see that the air resistance increases 9× if the speed increases 3×.

figure 5 Cyclists have to cope with air resistance.

EXAMPLE EXERCISE 2

In a tennis match, a tennis ball reaches a speed of 150 km/h. The ball's drag coefficient is 0.47 and its diameter is 6.6 cm. The density of air is 1.3 kg/m³.
Calculate the air resistance acting on the ball.

given
$v = 150\text{ km/h} = 41.7\text{ m/s}$
$C_D = 0.47$
$r = \frac{1}{2}d = 3.3\text{ cm} = 0.033\text{ m}$
$\rho = 1.3\text{ kg/m}^3$

required $F_{r,a} = ?$

working
$A = \pi \cdot r^2$ (The frontal cross-section is a circle.)
$= \pi \times 0.033^2 = 0.00342\text{ m}^2$
$F_{r,a} = \frac{1}{2} C_D \cdot \rho \cdot A \cdot v^2$
$= 0.5 \times 0.47 \times 1.3 \times 0.00342 \times 41.7^2 = 1.8\text{ N}$

So the air resistance is approximately 1.8 N.

Practice the concepts using the *Flash cards*.

COURSE MATERIAL

1 Answer the following questions.

a What creates the drag and the rolling resistance when you are riding a bicycle?

b How can you reduce the drag acting on your body when you ride a bike?

c Why might a racing cyclist pump the tyres of their bike up as hard as possible?

d What does Newton's First Law say about an object that is moving?

2 Describe the motion of an object:

a if the resultant is acting in the direction of motion?

b if the resultant on the object is 0 N?

c if the resultant acts against the direction of motion?

d if the resultant is perpendicular to the direction of motion?

IN PRACTICE

3 Mia is pulling her friend through the snow on a sledge. She pulls with a force of 50 N. The sledge moves through the snow at a constant speed of 4 km/h.

a What is the main force acting against the direction of motion and what causes it?

b Work out how big the resultant force is acting on the sledge.

4 Four forces are acting on a moving van: F_A, F_B, F_C and F_D (figure 6). To keep the drawing simple, the illustrator has all forces acting on the centre of gravity C.

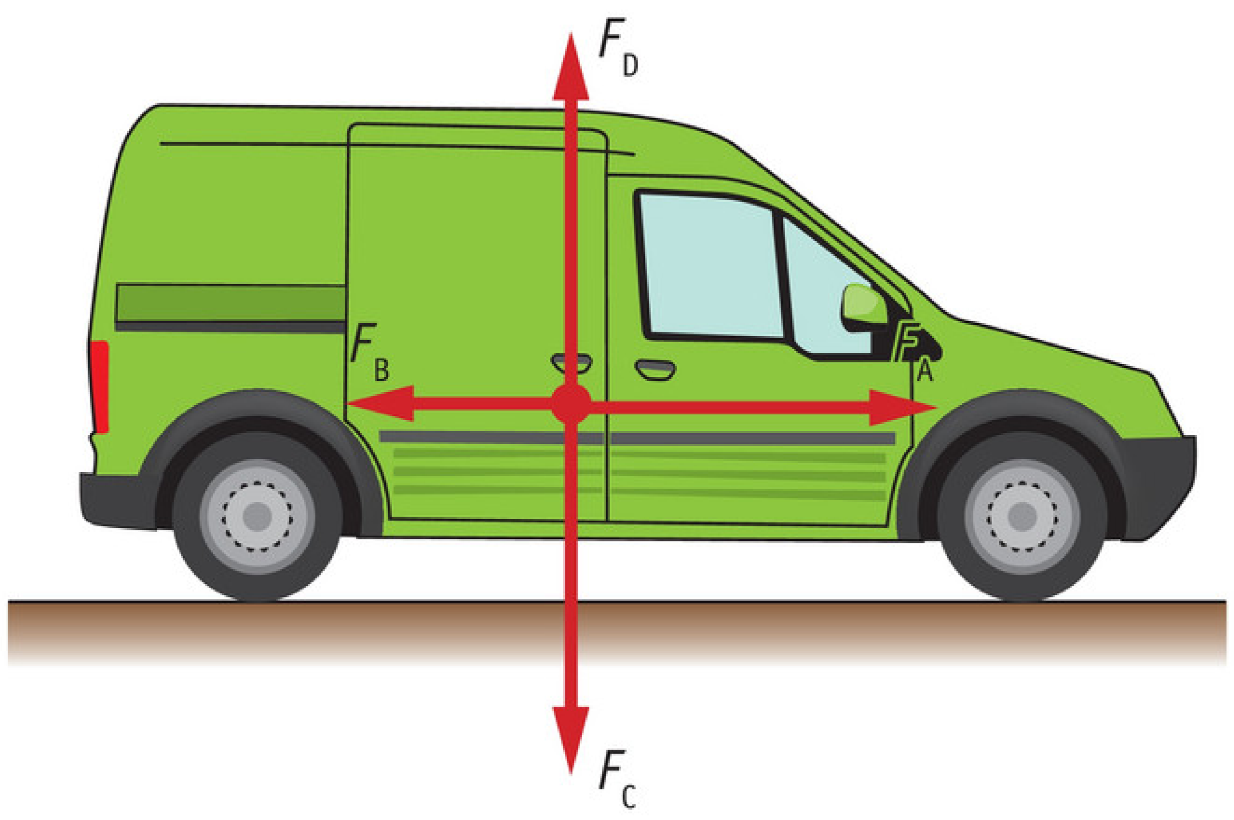


figure 6 The forces acting on a van.

a State the names of these four forces.

- F_A = ...
- F_B = ...
- F_C = ...
- F_D = ...

b The sizes of forces F_A and F_B can change.
When is F_B equal to 0 N?

c The van has an oil leak and it is losing one drop of oil every second. Figure 7 shows the oil trail that the van has left on the road, moving from left to right.
Describe the van's motion:
- between A and B
- between B and C
- between C and D

d Work out whether $F_A > F_B$, $F_A = F_B$, or $F_A < F_B$:
- between A and B
- between B and C
- between C and D

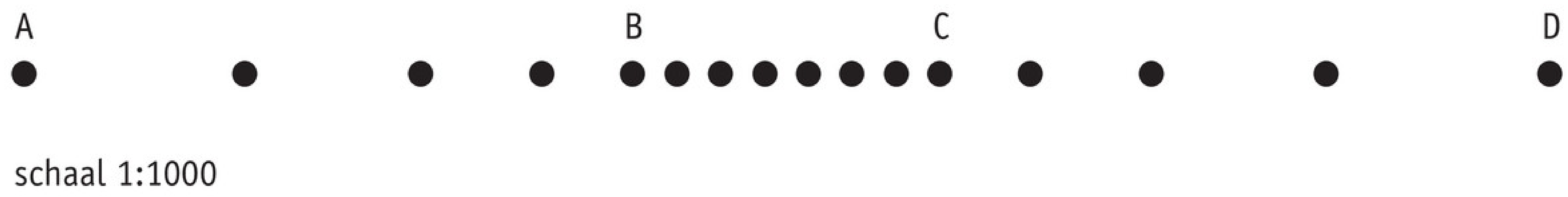


figure 7 The oil trail that the van left on the road.

5 Carla trains regularly on her racing bike. Figure 8 shows the relationship between the overall resistance and her speed.

a Carla starts by cycling for a while at a steady speed of 11 m/s.
How big is the driving force then?

b At a certain point, Carla starts pedalling faster. This means that a constant driving force of 40 N is applied to her bicycle for a while.
What is the resultant at the moment when she starts to accelerate?

c Determine the final (constant) speed that Carla achieves.

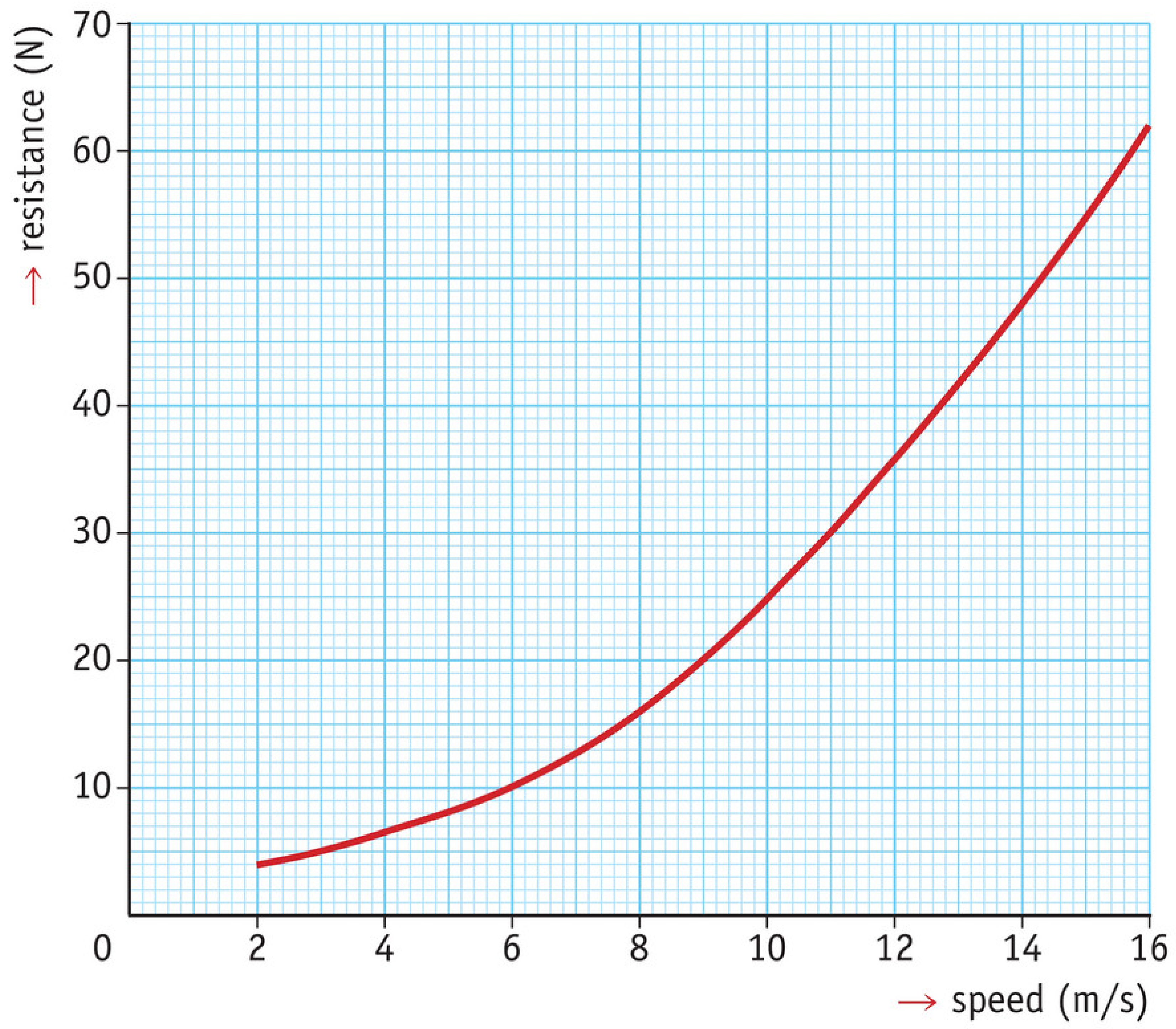


figure 8 The relationship between the speed and the overall resistance.

6 Zoe goes a short distance on her bike. Figure 9 shows the (v,t) diagram of her motion. The graph has been divided into five sections, A, B, C, D and E.

Is F_p greater than F_r, the same as F_r or less than F_r? Explain your answers.

a in part A of the motion

b in part B of the motion

c in part C of the motion

d in part D of the motion

e in part E of the motion

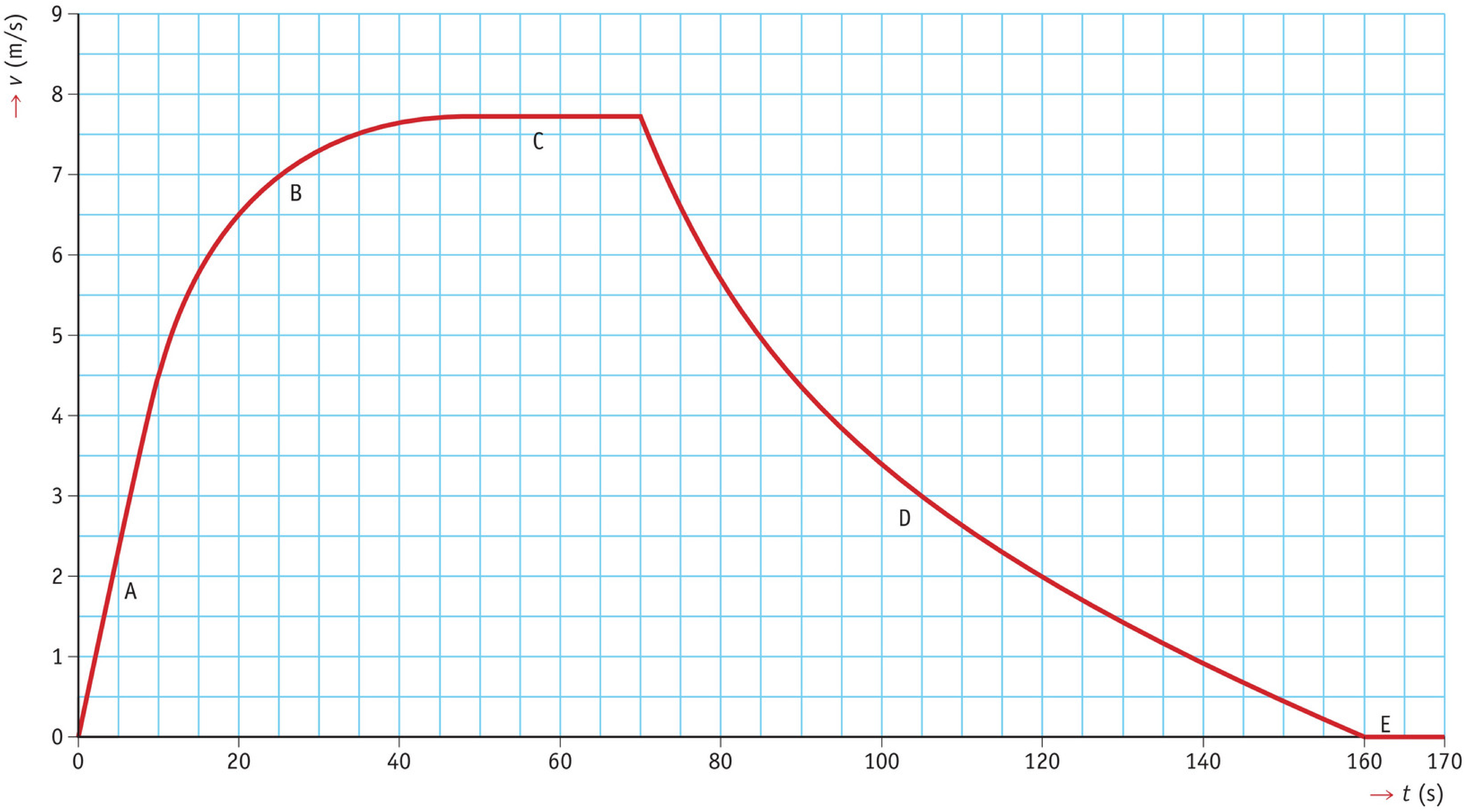


figure 9 The (v,t) diagram of Zoe's motion.

★ 7 Two forces act on a lift cage: gravity (F_g) and the tension in the cable (F_t). The size of the resistive force is negligible.

Compare the sizes of F_g and F_t in the following situations. Explain your answers.

a The cage is moving up and its speed is increasing.

b The cage is moving up at a steady speed.

c The cage is moving up and its speed is decreasing.

d The cage is suspended and not moving.

e The cage is moving down and its speed is increasing.

f The cage is moving down and its speed is decreasing.

8 A skydiver jumps out of a plane. Figure 10 shows you two snapshots of his jump. In both situations, the skydiver is falling at a constant speed.
When you compare the two situations, what can you say about:

a the size of the resultant?

b the speed?

c the magnitude of the air resistance?

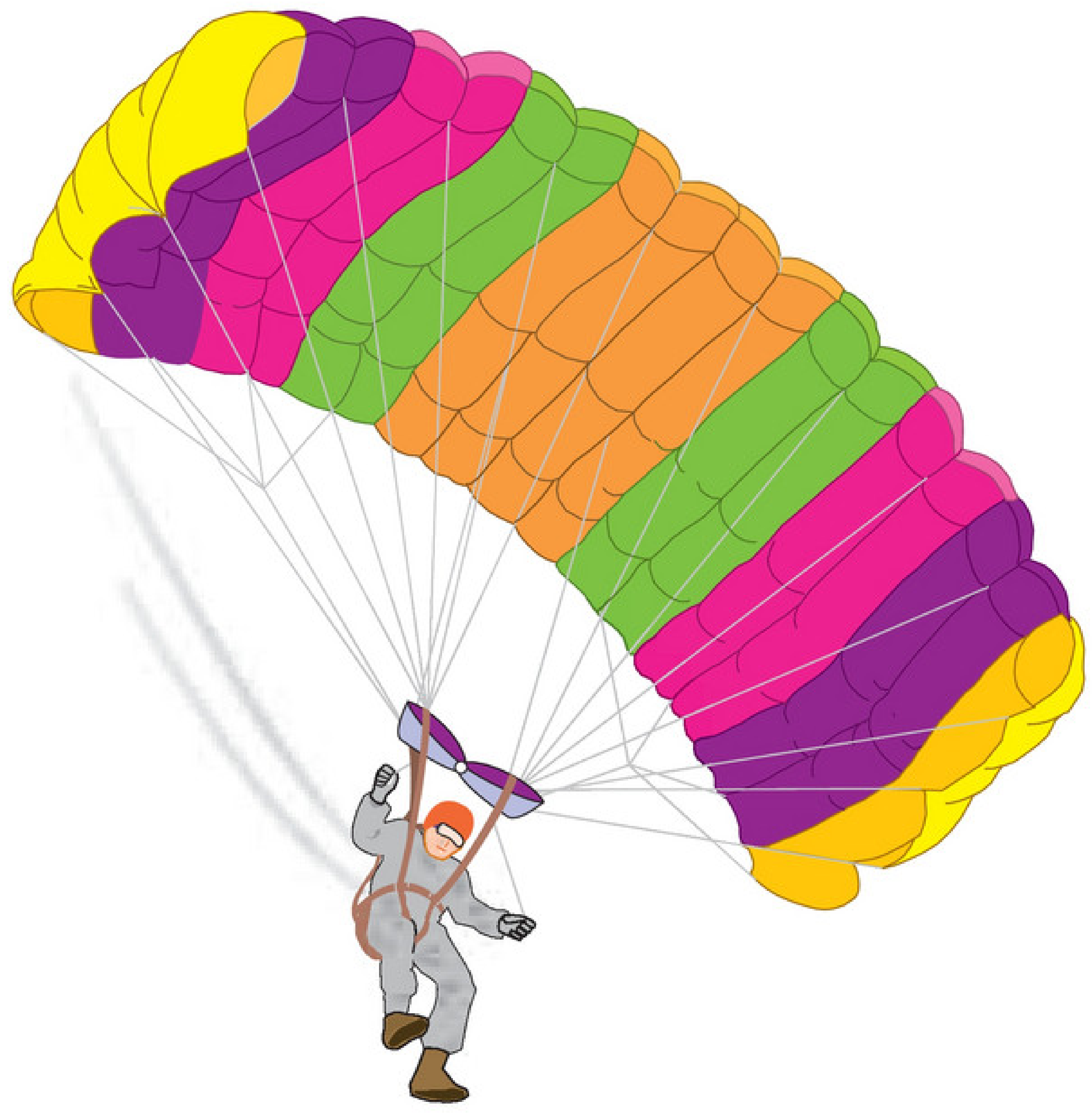


figure 10 A skydiver at two moments during his jump.

★ 9 A ball rolls from the bottom right to the top left along a curved edge as in figure 11.

a In figure 11, draw how the ball rolls after it leaves the curved edge. Explain your answer.

b An object can only travel in a circle if there is a resultant.
In figure 11, draw the resultant acting on the ball as it rolls along the edge.

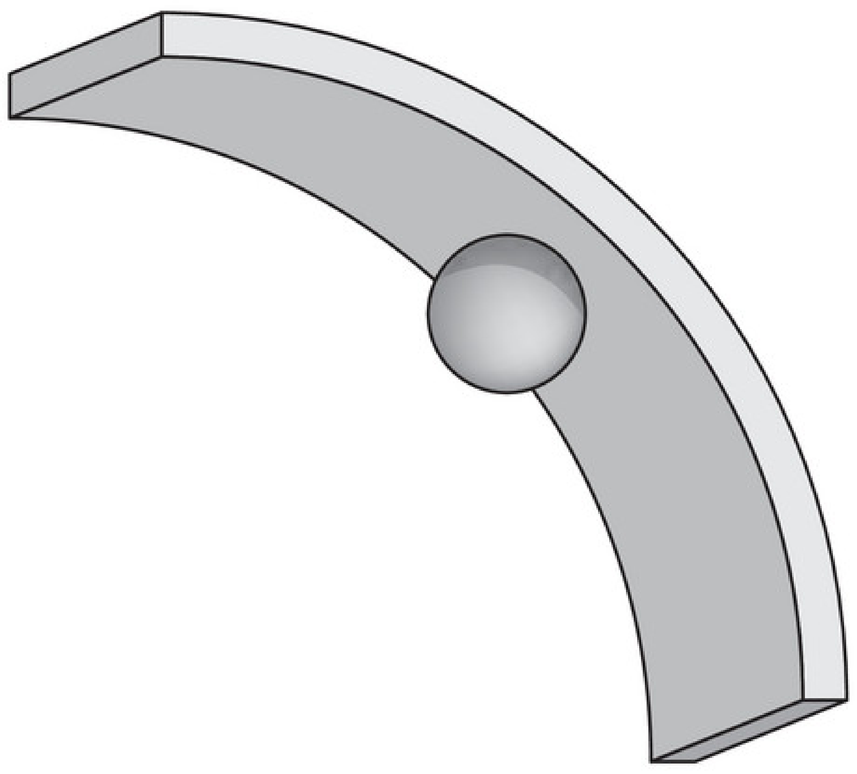


figure 11 A ball rolling along a curved edge.

Test what you know with *Test yourself*.

PLUS CALCULATING AIR RESISTANCE

10 Every object has its own resistance coefficient C_D (table 1).

table 1 C_D values for some moving 'objects'.

object	C_D
car	0.3-0.5
skier	0.9
touring cyclist	0.9-1.1
truck	0.6-1.0
racing cyclist/speed skater	0.7-0.9

a Explain the difference between the values of C_D for the touring cyclist and the racing cyclist.

b One car can have a smaller C_D value than another yet still face greater air resistance (at the same speed).
Explain why.

c Compare the air resistance of two trucks A and B. They both have the same frontal cross-section but the C_D value of truck A is 0.80 while that of truck B is 1.0.
Truck B is going twice as fast as truck A.
Explain how much greater the drag acting on truck B is than on truck A.

11 In indoor skydiving, you float in a vertical wind tunnel in which an air current is blown upwards with great force. Figure 12 shows Rosie (mass 65 kg) floating on the air current just above the ventilation grille. The air (density 1.29 kg/m^3) is blown upwards at 200 km/h.

a Do a calculation to estimate the value of Rosie's drag coefficient C_D in this position.
Work out first which variable you need to estimate.

b If Rosie brings her arms closer together and lifts up her lower legs, her frontal cross-section will decrease. Assume her C_D value doesn't change.
Explain whether Rosie will move upwards or downwards.

c If the speed of the airflow increases by 8%, Rosie is able to float in the same way as in Exercise (a) while holding her arms and legs in the new position. Calculate how much the new position reduced her frontal cross-section by. Assume again that her C_D value hasn't changed.

figure 12 Floating on an airflow.

4 Forces in the universe

LEARNING OBJECTIVES

2.4.1 You can describe the structure of the solar system (sun, planets and their motions).
2.4.2 You can explain why planets always orbit the sun in an ellipse.
2.4.3 You can explain that gravity is the centripetal force in the solar system.
2.4.4 You can work out why an object or person in free fall is weightless.
2.4.5 You can explain why astronauts in a space station are permanently weightless.
PLUS 2.4.6 You can resolve a force into two components using a construction method.

For a long time, scientists thought that gravity was something that only applied close to the Earth. They believed that stars and planets were located in the 'heavenly spheres', far beyond the influence of gravity. That idea turned out to be wrong. Gravity is present throughout the universe and it determines how stars, planets and moons move.

THE SOLAR SYSTEM

The Earth is one of the planets in the solar system (figure 1). Like Mercury, Venus and Mars, Earth is one of the terrestrial planets. These planets are relatively small and have rocky surfaces. The gas giants Jupiter, Saturn, Uranus and Neptune are much larger. They consist almost entirely of gases and do not have a surface that you could walk on.

figure 1 The solar system (not to scale).

The distances in the solar system are enormous. Compared with those distances, the planets themselves are very small. The Earth is 150 million km away from the sun on average, whereas the Earth's diameter is only roughly 13 thousand km. That is why the solar system in figure 1 is not drawn to scale: otherwise you would not be able to see the planets at all and even the sun would be no more than a dot.

The planets go around the sun in elliptical orbits. An ellipse is a geometric shape that looks like a squashed circle. Figure 2 shows you how you can draw an ellipse using two drawing pins, a piece of string and a pencil. The places where you put the drawing pins are called the **foci** (plural of **focus**) of the ellipse. The smaller the distance between the foci, the closer the ellipse is to a circle. The ellipses of the planets' orbits are almost circular.

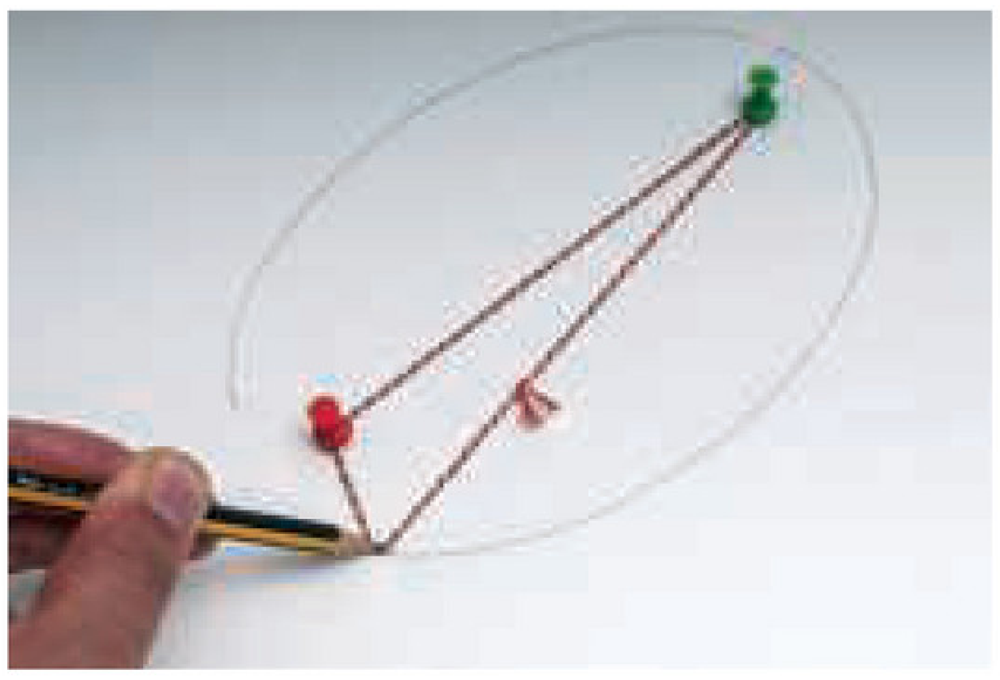


figure 2 How to draw an ellipse.

It takes the Earth one year to go round the Sun once. In addition to their orbits around the sun, the planets also rotate around their own axes. The Earth, for example, takes nearly 24 hours to rotate around the line that runs from the North Pole through the middle of the Earth to the South Pole. The reason why a day (24 hours) is slightly longer than the full rotation around the axis is that the Earth's orbit around the sun also makes a small contribution to the day length.

THE ROLE OF GRAVITY

The structure of the solar system was already known in Isaac Newton's time. Scientists had a good idea of the distances between the sun and the planets. They knew that the planets orbited the sun in ellipses and that the sun was always one of the foci. But they could not explain why the planets would move like that.

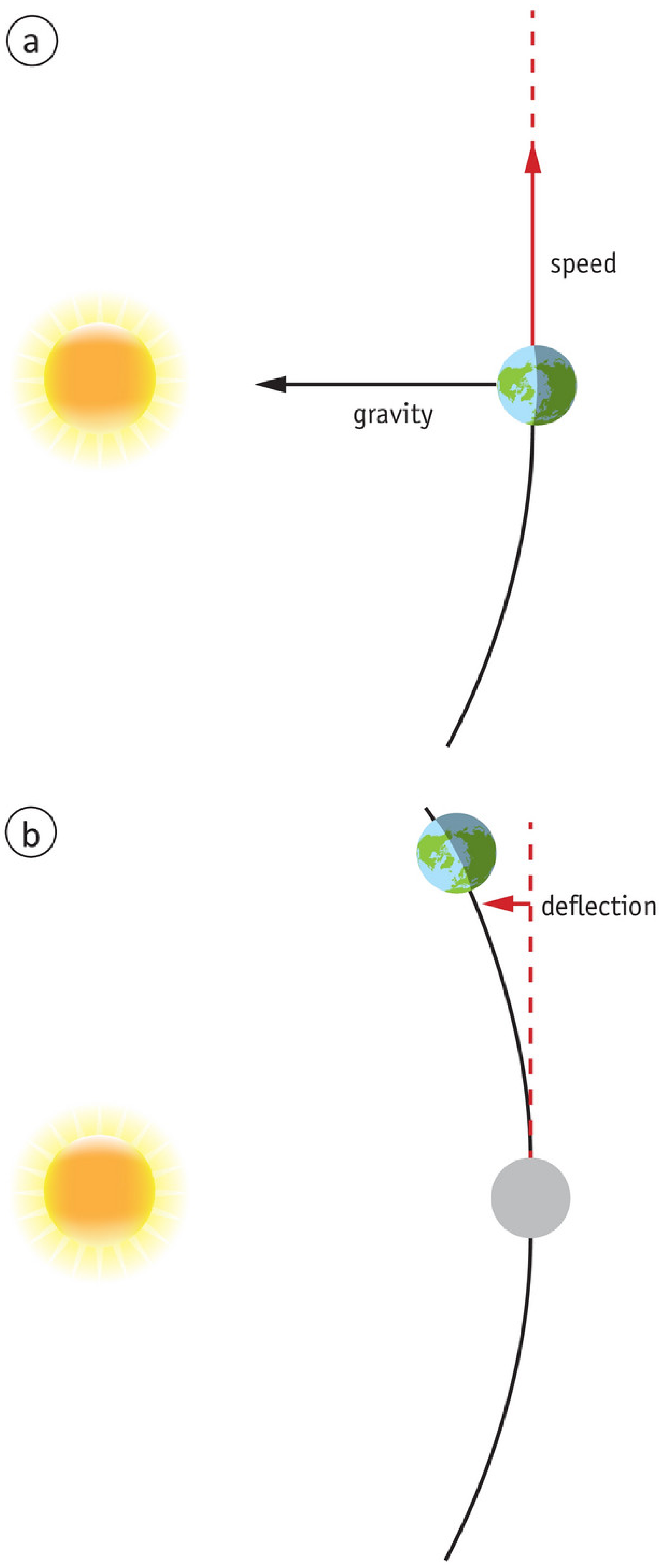
Newton considered how a planet would move if the sun was not there. According to his First Law, the planet would then move at a constant speed in a straight line. There would then be no forces causing changes in the planet's movement.

His next question was what force was making the planets deviate from that straight line? Why does the planet not keep moving in the same direction, like a tennis ball after you have hit it? After all, the tennis ball does not travel in a big curve and come back to you. So why does a planet have an elliptical orbit around the sun?

Newton came to the conclusion that gravity was responsible. In the same way as an apple that falls out of a tree is attracted to the Earth, a planet is attracted to the sun. The reason why a planet does not fall into the sun is because it is moving at high speed. Gravity plus the planet's own motion combine to keep the planet in orbit around the sun.

Figure 3 shows how this works. As you can see, gravity acts perpendicularly (or almost so) to the direction of motion of the planet (figure 3a). This means that the planet does not move in a straight line, but instead bends in the direction gravity is pulling (figure 3b). And that effect is present all the time: gravity pulls continually on the planet so that it ultimately travels in a complete ellipse around the sun.

figure 3 The effect of gravity on the motion of a planet.



THE CENTRIPETAL FORCE

In any form of circular motion, there is a **centripetal force** that keeps making the object deviate. In the solar system, gravity is the centripetal force: it makes the planets orbit the sun. Figure 4 shows you another situation in which an object is rotating. Here it is the athlete's muscle strength (transmitted via a steel cable) that keeps the ball rotating around the hammer-thrower.

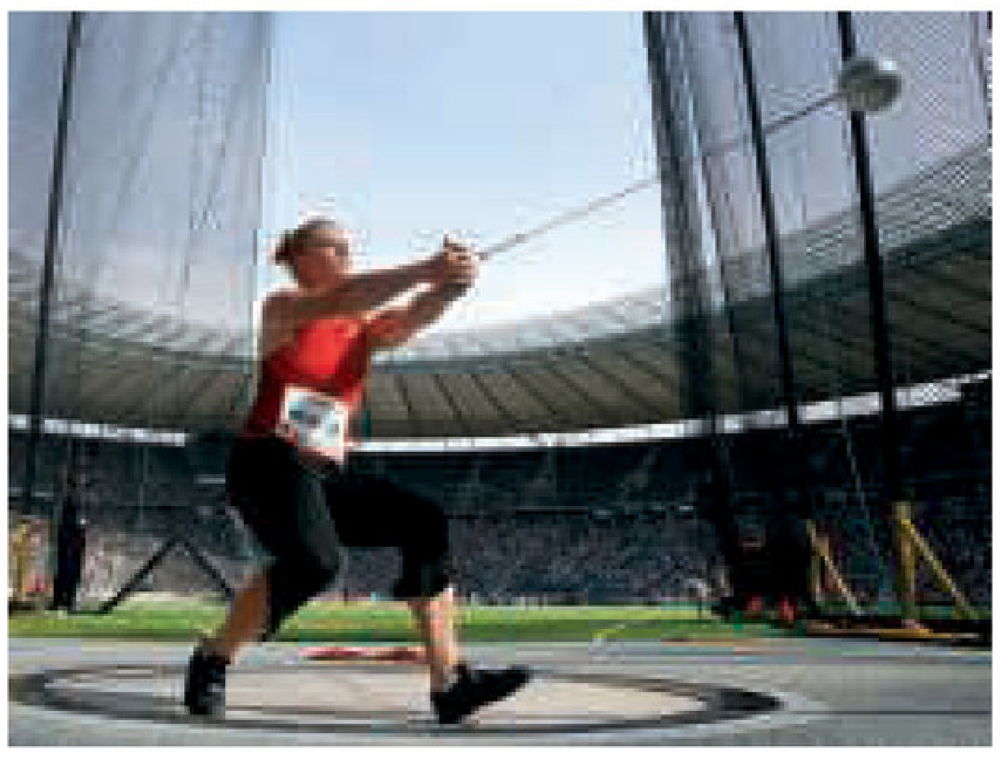


figure 4 A lot of strength is required to keep changing the direction that the hammer is moving in.

Newton thought that gravity was inversely proportional to the square of the distance between two objects. If an object is twice as far from the sun, the gravitational force acting on it is four times smaller, because $2^2 = 4$. If an object is three times as far from the sun, the gravitational force acting on it is nine times smaller, because $3^2 = 9$. Newton could prove mathematically that in this case, gravity gave the centripetal force for the observed motion of the planets.

Newton's theory was soon being applied to other objects in space such as comets (figure 5). Their orbits and the time one orbit took could be calculated using Newton's theory. The English astronomer Edmund Halley predicted that a certain comet would return to the skies after 76 years and that was precisely what happened in 1758 (16 years after Halley's death). Such successful predictions gave Newton's ideas a lot of authority in the eighteenth century.

figure 5 Halley's comet when it last returned in 1986.

FREE FALL AND WEIGHTLESSNESS

If you stand on a floor on Earth, your feet exert a force on the floor. That force is your **weight**. Your weight disappears when you jump. Your body is then momentarily in **free fall**; for just a few tenths of a second, the only force acting on your body is gravity. Because your body is not supported by anything, you are **weightless** for a moment. But because the jump only lasts for a very short while, you don't really experience what weightlessness is like. In a parabolic flight (figure 6), however, you are in freefall for longer and the feeling of weightlessness is genuinely there.

A space station that is orbiting the Earth is permanently in free fall. The space station moves without being driven forwards. The only force acting on the space station is the Earth's gravity. It therefore moves in an ellipse around the Earth, with the Earth's gravity as the centripetal force. The astronauts in the space station are also moving in free fall and are therefore permanently weightless. The weightlessness of astronauts floating in a space station is a good example of Newton's theory.

Parabolic flight

If you have plenty of cash to spare, there is one attraction that you might enjoy: a parabolic flight. During a parabolic flight, which is done on an Airbus A300, the pilot flies sharply upwards and can then make the aircraft drop in freefall for about twenty seconds. During those twenty seconds, the conditions on board mean that everything is weightless, or to use the official term, in microgravity. A single flight consists of thirty such parabolas. Flights such as these are used for getting future astronauts accustomed to weightlessness in the space station.

Source: The new star

figure 6 Weightlessness training for future astronauts.

PLUS THE ELLIPTICAL ORBIT OF A COMET

The comets in our solar system are much smaller than the planets. They consist of ice, gas and materials and are therefore also called 'dirty snowballs'. The craters on the Moon and the planets are evidence that there have been a lot of comet impacts. Astronomers are very interested in comets. They investigate whether comets brought some of the water that is now on Earth, for example, and the study the role of comets in the origins of life on Earth.

The comets' orbits are different to the orbits of the planets. The planets' orbits are nearly circular whereas the comets' orbits are very flat ellipses (figure 7).

Like the planets, gravity makes a comet stay in its orbit. The force due to gravity that the sun exerts on the comet always points in the direction of the sun. For a planet, the force due to gravity is almost perpendicular to the direction of motion but you can see from figure 8 that this is not the case for a comet. The force due to gravity is at an angle to the direction of motion of the comet.

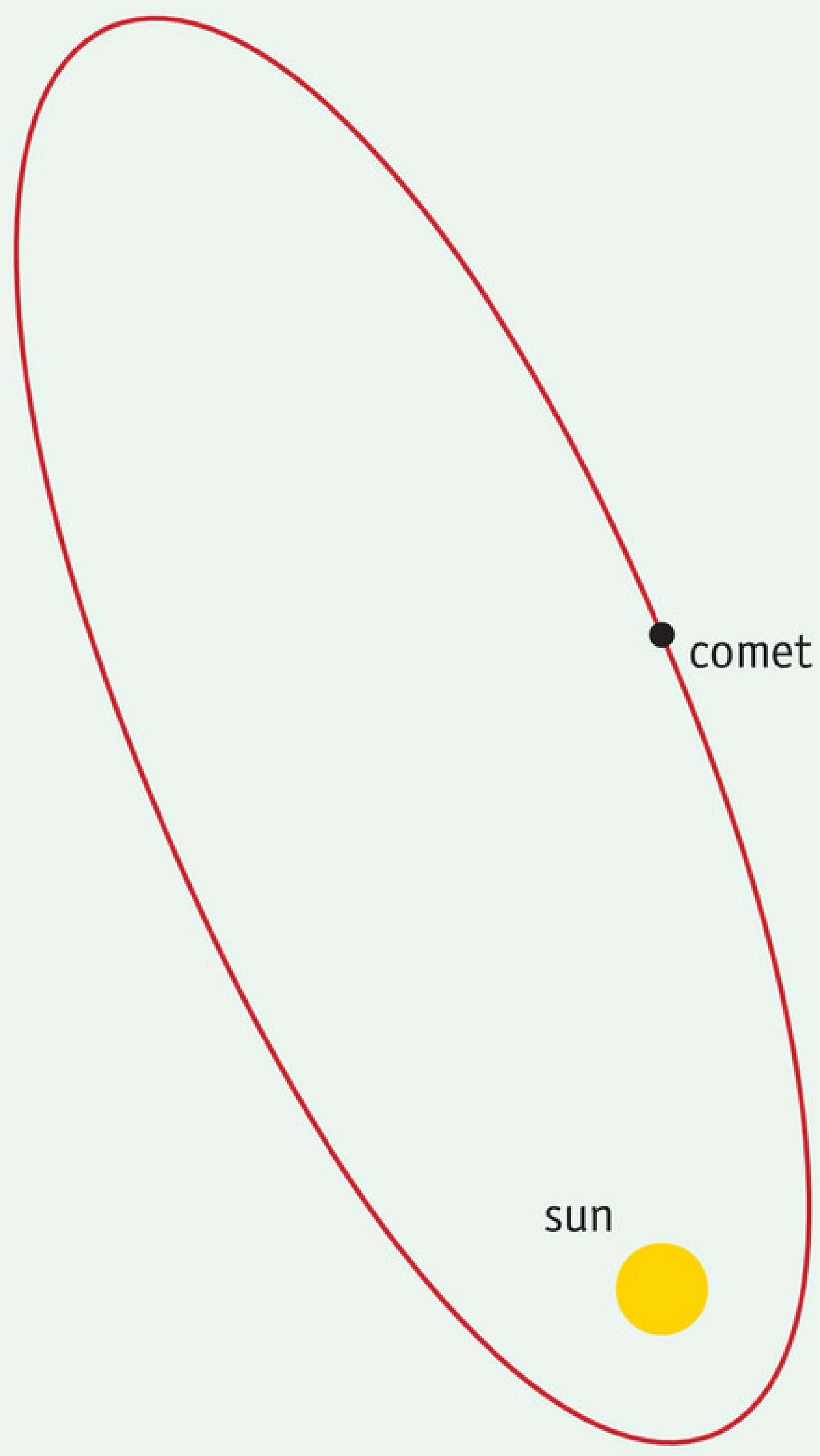


figure 7 The elliptical orbit of a comet that orbits the sun anticlockwise.

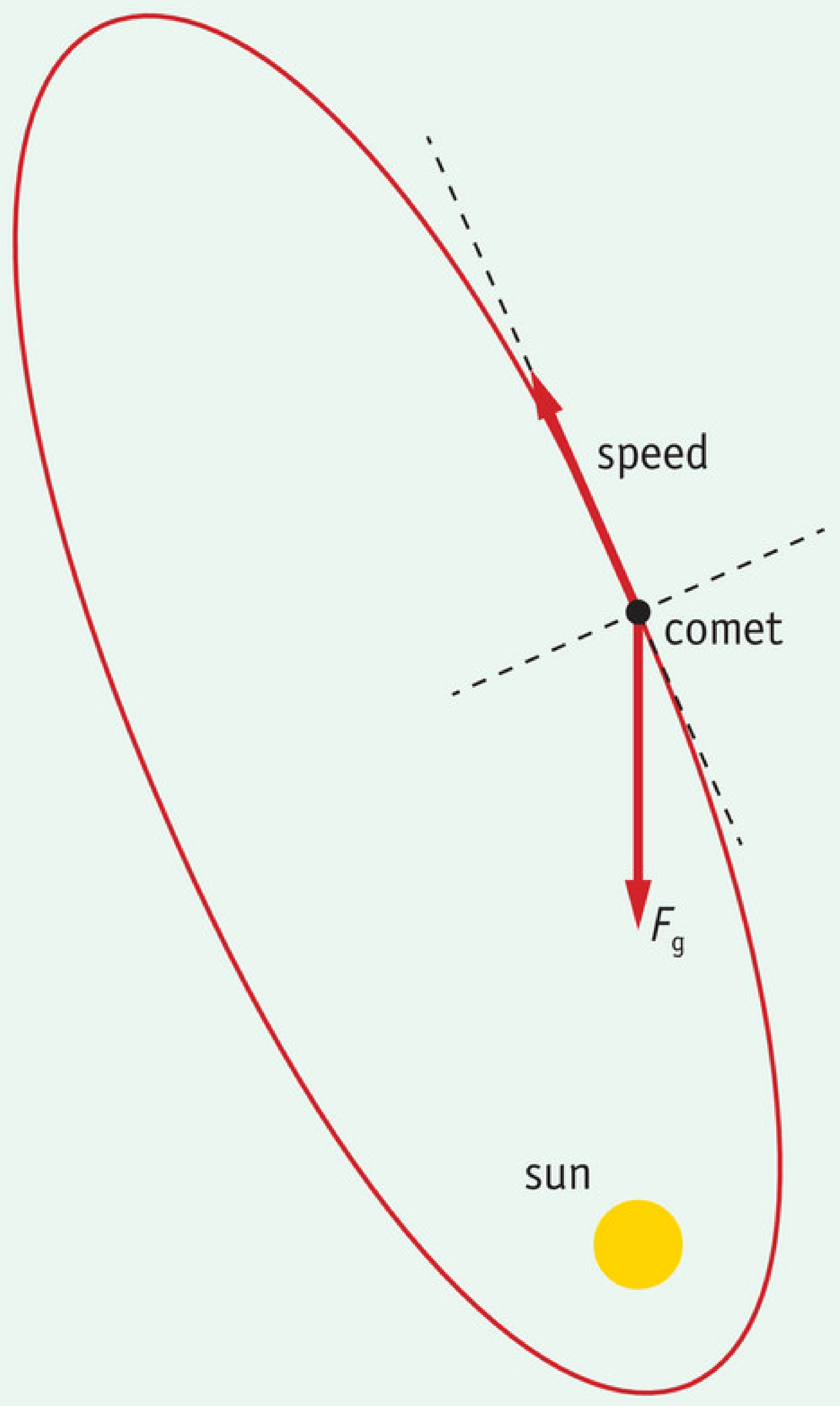


figure 8 The force of gravity acting on the comet points in the direction of the sun.

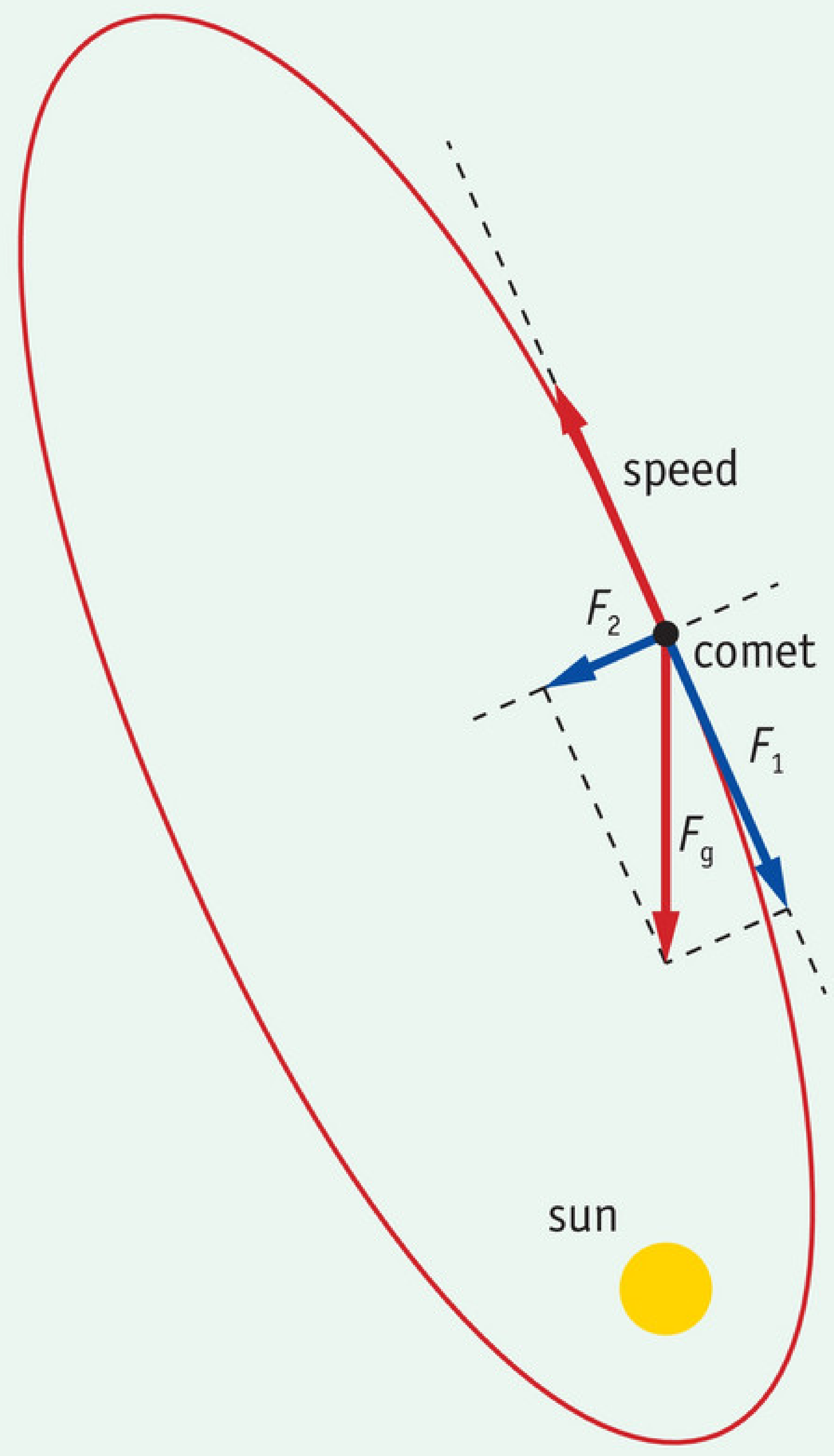


figure 9 The force of gravity acting on the comet, resolved into two components.

In this chapter, you learned how to determine the resultant of two forces using the parallelogram of forces. But if you know the resultant and don't know the forces, you can also use the parallelogram method to determine which two forces combined to give this resultant. This is known as **resolving** the force into two **components**. Figure 9 shows how the resultant F_g is resolved into two components using the parallelogram method: F_1 acting against the direction of motion of the comet and F_2 perpendicular to that.

Each of the components has an effect on the comet's motion:

- F_1 causes a change in the speed of the comet. In figure 9, F_1 acts against the motion and therefore causes deceleration. F_1 changes the speed but not the direction.
- F_2 acts perpendicularly to the direction of motion. As in a planet, F_2 acts as a centripetal force that makes the comet change course. F_2 changes the direction but not the speed.

Practice the concepts using the *Flash cards*.

COURSE MATERIAL

1 Answer the following questions.

a Why doesn't the Earth fall in a straight line towards the sun?

b What force acts as the centripetal force keeping the planets in their orbits?

c The force that an object exerts on its support is called ....

d Under what circumstances are you continually weightless?

2 Give an example of a situation:

a where your weight and the force of gravity upon your body are equal.

b where your weight and the force of gravity upon your body are different.

IN PRACTICE

3

Martin is going to make a model of the solar system. He wants to use a marble with a diameter of 1.3 cm for the Earth.

a What is the diameter of the Earth in reality?

b What scale will Martin therefore be using for his model?

c The diameter of the sun is in reality 1.4 million kilometres.
What would be the diameter of the sun in Martin's model?

d Astronomers often express distances in astronomical units (AU). One astronomical unit is equal to the average distance between the Earth and the sun.
What is 1 AU in metres (roughly)?

e How far is 1 AU in Martin's model?

f Neptune, the eighth planet and the most distant of the planets, is an average of 4.5 billion kilometres from the sun.
Express this distance in AU.

g For even larger distances, astronomers use a unit called a lightyear (the distance light travels in one year).
Look up the speed of light and work out how many kilometres one lightyear is.

4

Exoplanets are planets that have orbits around stars other than our Sun. Hundreds of exoplanets have been discovered in recent years. Some of these planets have highly elliptical orbits (figure 10).

Grilled planet

One of the planets that has been discovered outside our solar system gets so close to its sun that it warms up by as much as 700 degrees Celsius in a couple of hours. The planet – a gas giant with the creative name of HD 80606b – is located about two hundred light-years away from the Earth. It is about four times heavier than Jupiter and orbits its sun in 111 Earth days.
The orbit of this planet is elliptical, with the star at one of the foci. At some moments the planet is as far away from its sun as the Earth is, but at others it is only one thirtieth that distance.

Source: www.wetenschap24.nl

figure 10 An exoplanet with an exotic orbit.

a Sketch what the orbit of the exoplanet HD 80606b looks like.
Draw the star in one of the foci.

b How is this orbit different from the planetary orbits in our solar system?

c Why is it a good thing that the Earth does not have an orbit like HD 80606b?

★ 5 Satellites go around the Earth in the same way as the planets go around the sun. A satellite in a low Earth orbit (LEO) goes around at an altitude of 160 km to 2000 km above the Earth's surface. It is slowed down to some extent by the extremely rarefied atmosphere at those attitudes.

a Explain how the satellite's orbit changes as it slows down.

b Will the satellite be slowed down more, the same amount or less in its new orbit as described in (a)? Explain your answer.

c Explain what will ultimately happen to the satellite when its fuel runs out.

6 Use the Internet to find a video of an athlete throwing the hammer.

a Describe how the ball moves before the athlete lets go of the handle.

b Describe the movement after the athlete has let go of the handle.

c Explain the difference between the movements in exercises (a) and (b). Use the term 'centripetal force'.

7 In the circus, six acrobats are performing an act. Jeremy (70 kg) is perfectly balanced (figure 11).

a Which three forces are acting on his body?

b What is the term for the force that Jeremy is exerting on Patrick's head?

c Approximately how large is that force? Explain your reasoning.

d A short while later, Jeremy jumps down with a double somersault.
Explain whether:
- the force due to gravity acting on his body changes as he does this.
- his body's weight changes as he does this.

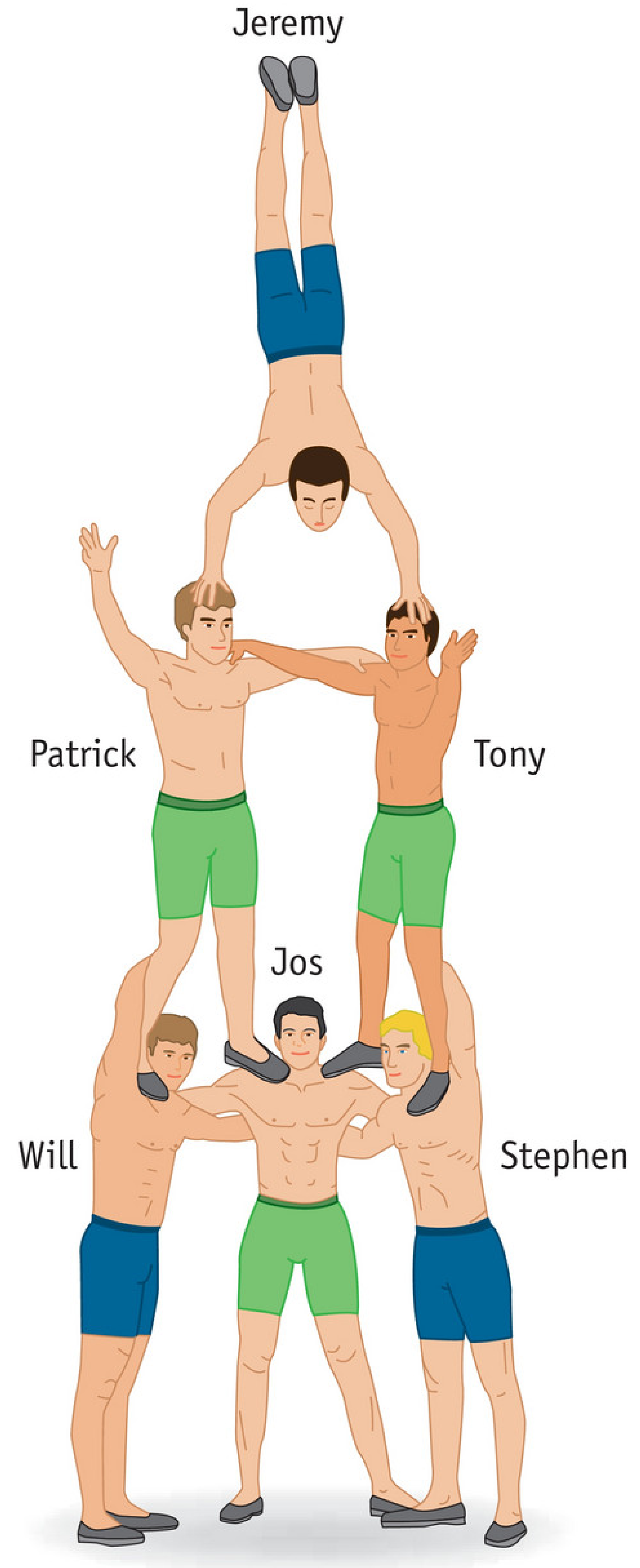


figure 11 A circus act.

8 It has been possible since 2004 to spend a few minutes in space by travelling in the spacecraft SpaceShipOne. A specially designed plane (the White Knight) takes SpaceShipOne to an altitude of approximately 15 km, where the spaceship is let loose. Figure 12 shows a schematic drawing of the flight. Five points have been drawn in: a, b, c, d and e.

Explain whether the passengers experience weightlessness:

a between point a and point b;
b between point b and point c;
c between point c and point d;
d between point d and point e.

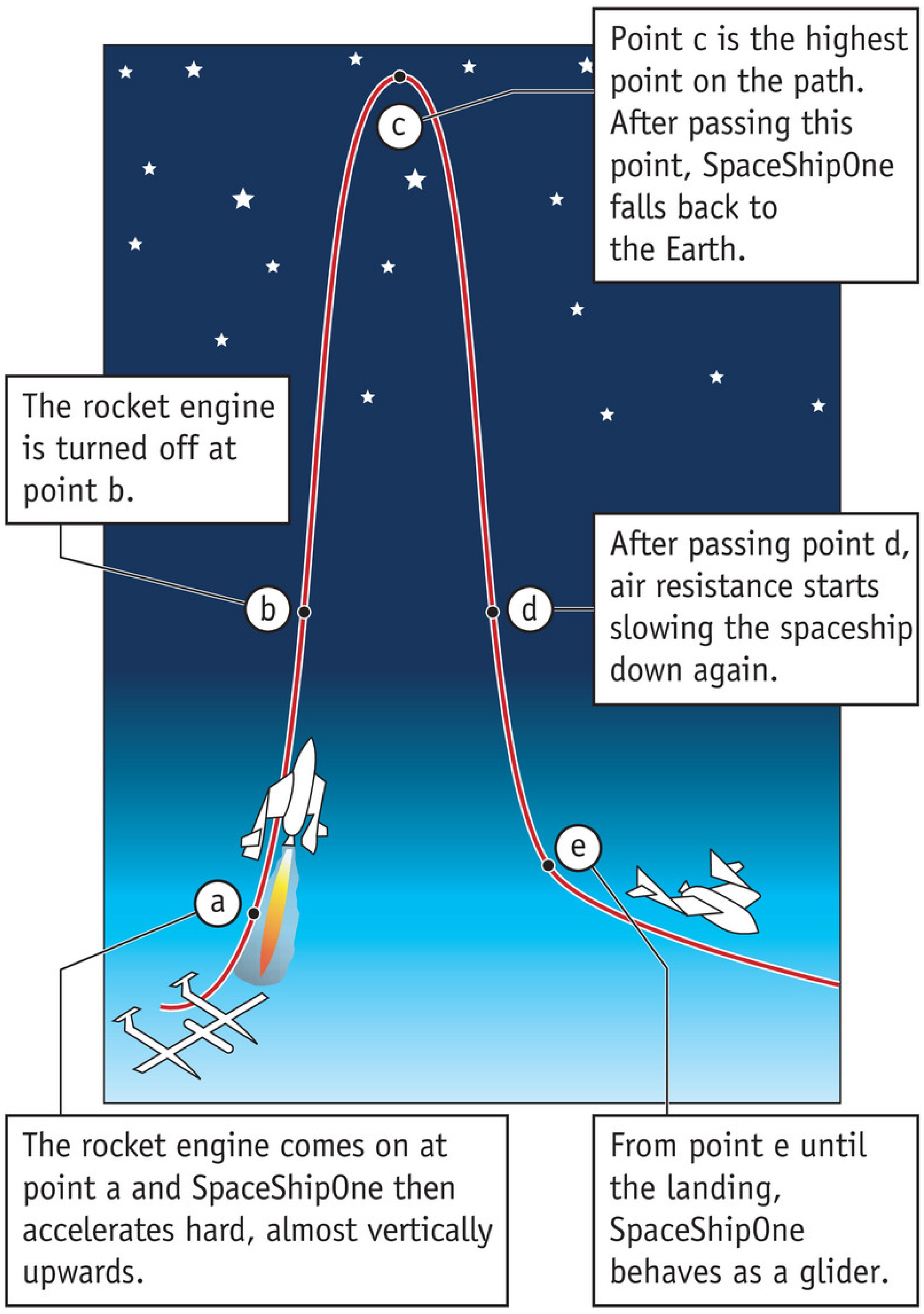


figure 12 The flight path of SpaceShipOne.

Test what you know with *Test yourself*.

PLUS THE ELLIPTICAL ORBIT OF A COMET

9 Figure 13 shows the comet from figure 8 at another point in its orbit.

a Explain why the force due to gravity acting on the comet at this point of the orbit is less than in figure 8.

b In figure 13, draw the component F_1 in the direction of motion and the component F_2 perpendicular to that.

c Explain the effect each component has on the comet's motion.

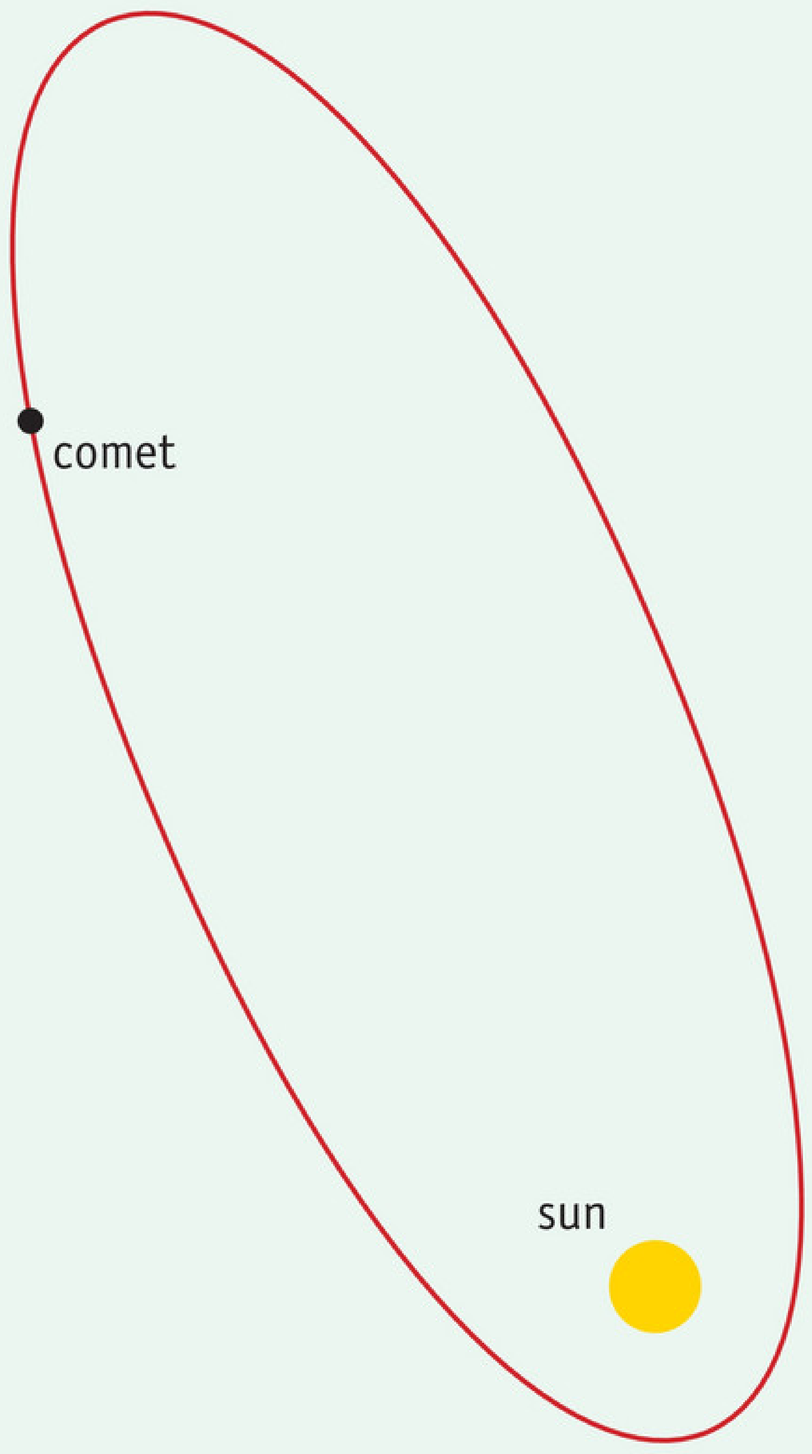


figure 13 The comet at another point in its orbit.

10 Figure 14 shows a comet orbiting the sun in a wide ellipse. The sun is at one of the two foci.

a In figure 14, indicate the points in the orbit at which the force due to gravity is perpendicular to the comet's direction of motion. At those points, indicate the direction of the speed and the direction of the force due to gravity.

b Explain which points the comet's speed is decreasing between.

c Explain where the speed is greatest and where it is smallest.

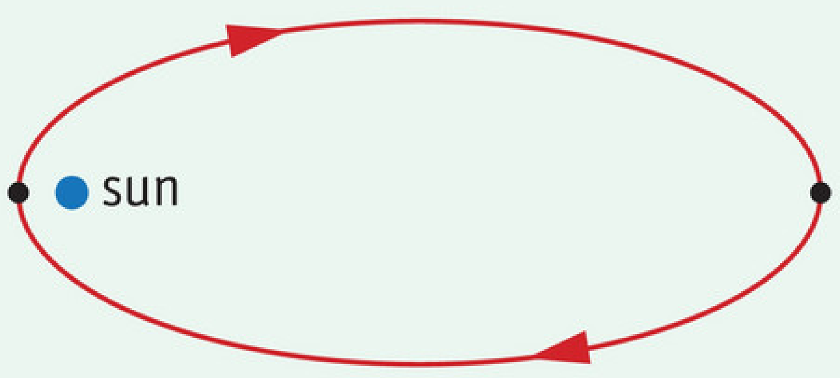


figure 14 A comet's orbit around the sun.

Experiments

EXPERIMENT 1 STRETCHING A HELICAL SPRING

30 minutes

Introduction

A helical spring stretches if you hang weights on it. The extension is the number of centimetres by which the length of the spring increases. If a spring is 12.0 cm long with no weights on and 15.8 cm with the weights, the extension is then 3.8 cm.

Purpose

The question you are studying is:
What is the relationship between the force used to stretch a spring and the extension?

Requirements

- ☐ stands
- ☐ weight carrier
- ☐ weights
- ☐ coil spring
- ☐ ruler

Doing the experiment and writing it up

- Set the experiment up as shown in figure 1.
- Hang the weight carrier on the spring, but with no weights.
- Note the position of the bottom of the coil spring.

....

....

- Then put one, two, three etc. weights successively on the weight carrier.
- Determine the corresponding extension of the spring each time (= position – zero position).

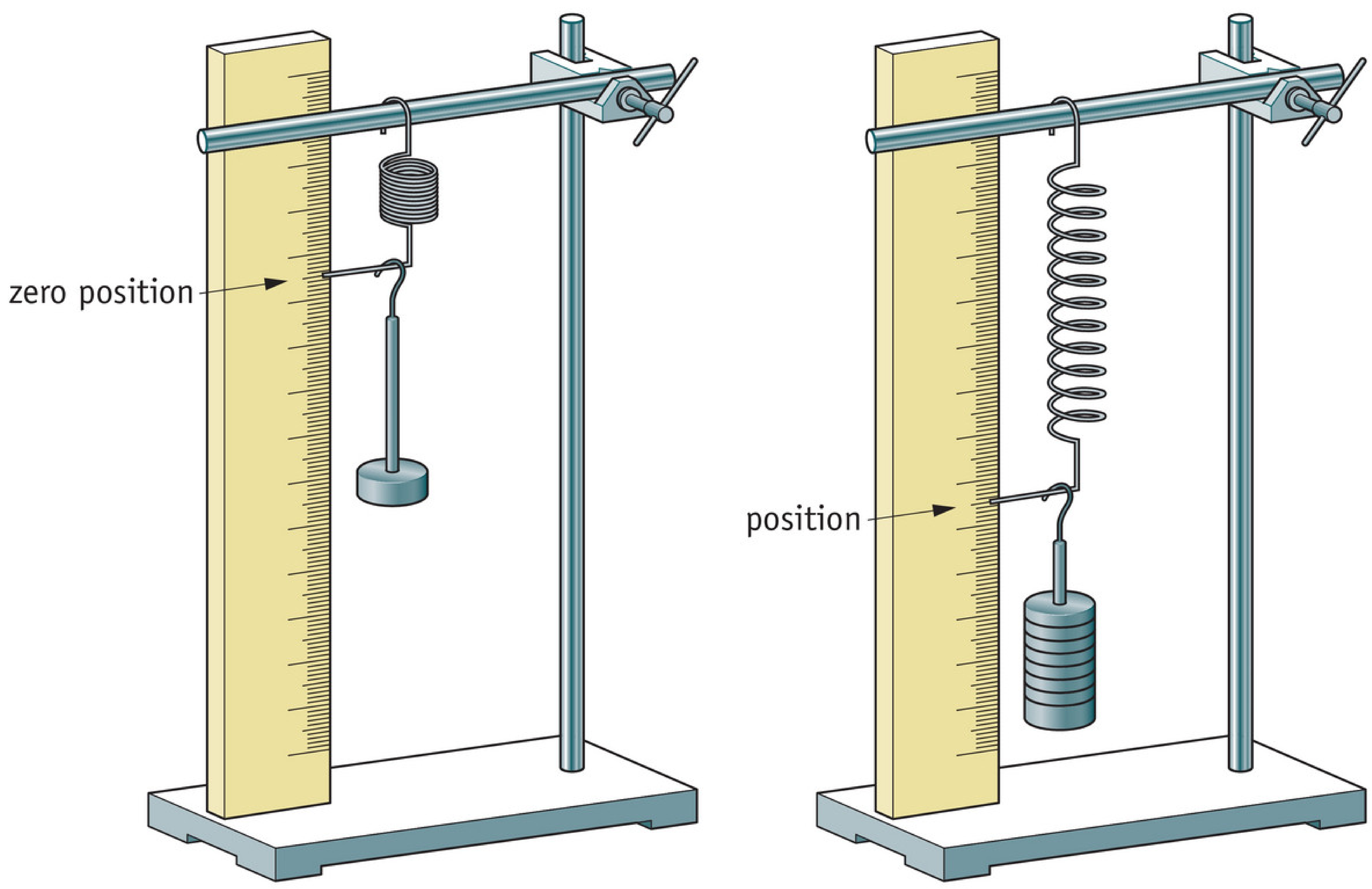


figure 1 The setup for Experiment 1.

1 Note down the mass of the weights, the force on the spring and the corresponding extension in table 1.

table 1 The measurement data from Experiment 1.

number of weights	mass of weights (g)	force on the spring (N)	extension (cm)
0	0	0	0
1			
2			
3			
4			
5			
6			
7			

2 See the skills section on *Working with tables and graphs*.
Make a graph of your measurements.

3 See the skills section on *Measuring relationships*.
What kind of relationship is there between the force on a spring and the extension?

The spring constant C gives the stiffness of the spring. The formula for the spring constant is $C = \frac{F}{u}$

If you fill in F in newtons (N) and u in metres (m), you will get C in N/m.

4 Use the graph to determine the spring constant of this spring. Write down how you did this.

....

....

....

....

....

5 Answer the study question.

....

....

....

....

Your teacher will tell you whether or not you have to write up a report on this experiment.

EXPERIMENT 2 BUILDING AND CALIBRATING A DYNAMOMETER

45 minutes

Introduction

Imagine that a factory making measuring instruments is going to launch a new model of dynamometer that allows forces to be measured accurately. A helical spring has been chosen for the new meter. Your job is to complete the design by adding an accurate and easily readable graduated scale.

Purpose

You will be making a graduated scale that meets the following requirements.

Design requirements

- The measurement range of the dynamometer must be at least 0 to 1 N.
- The distance between the marks on the graduated scale must represent no more than 0.1 N.
- The dynamometer must be at least as accurate as an ‘ordinary’ dynamometer.

Requirements

The basic setup has been drawn in figure 2. Make your own list of what you will need.

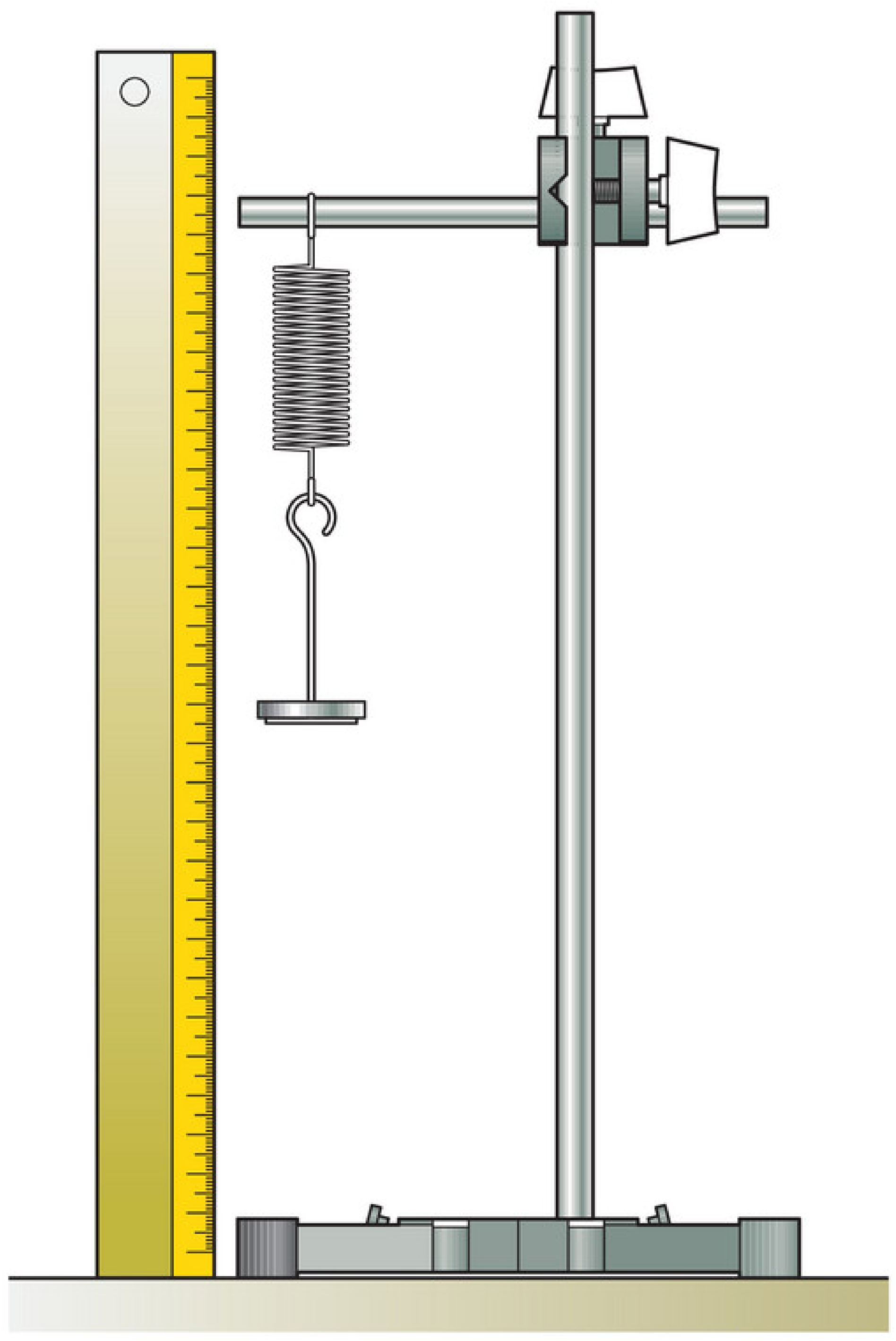


figure 2 The setup for Experiment 2.

Doing the experiment and writing it up

1 Explain how you are going to calibrate the dynamometer.

....

....

....

....

2 Make a note of the practical equipment you will need.

....

....

....

....

....

- Get your teacher to check the list of practical equipment and the calibration method.
- Construct the dynamometer and give it a graduated scale. Then test whether it meets the design requirements.

3 Explain how you carried out the test.

....

....

....

....

- Make improvements if necessary.
- Make a new graduated scale if necessary.
- Finally, get your teacher to assess the dynamometer.

4 If you have to write up a report of this experiment, include:

a a photo of the setup, including the calibrated graduated scale;
b how you made the graduated scale;
c the various ways in which you tested the graduated scale;
d your conclusions: how accurate is the dynamometer?

EXPERIMENT 3 CARRYING OUT AN EXPERIMENT – THE ROLLING RESISTANCE OF A BICYCLE

45 minutes

Introduction

Suppose a sports scientist writing in a magazine for amateur racing cyclists states, “Many amateur racers do not realise how important the correct tyre pressure is. If the tyres are pumped up hard, you are quicker: a couple of bar more and the rolling resistance can be reduced by as much as 20%. In a time trial in a cycle race, the difference that can make could be several tens of seconds.”
You wonder whether the sports scientist is right and you decide to do an experiment.

Purpose

The question you are studying is:
How does the rolling resistance of your bicycle vary with the pressure in the bike tyres?

Doing the experiment and writing it up

- Think about how you can give the most reliable answer to the question. What is your test setup going to look like; what exactly are you going to measure; how will you make sure that the measurements are repeatable (and can therefore be verified)?

1 Make a work plan for this study.
- Talk it through together to discuss any risks there might be. What can you do to make sure that this experiment can be carried out safely?
- The work plans are then discussed with the rest of the class. After this, you can improve your work plan if necessary.
- Then carry out the experiment.

2 See the skills section on *Writing a report*. Make a report of this experiment in which you answer the research question.

Tips

- First think about how you can make the effect of air resistance on your measurements as small as possible.
- Draw a graph of the rolling resistance against the pressure in the bike tyres.

The forces on Epke Zonderland

It is Sunday, 14 April 2019. At the European Gymnastics Championships in Szczecin (Poland), the Russian Artur Dalaloyan has just given an amazing performance for which the jury gave a score of 14.800 points. Now it is Epke Zonderland's turn. To become the champion, he has to take risks.

Epke is lifted onto the horizontal bar and given a small push so that he swings back and forth. In the next swing, Epke lifts his legs up into the air to far above the bar. Now he swings backwards with more speed. Once again, his legs go straight up in the air and now Epke swings into a handstand on the bar.

FLYING SHOW

Epke does some simple exercises for a few seconds but after twelve seconds he pulls hard on the bar as he swings upwards. This makes the bar vibrate visibly, like a guitar string. Epke now swings down at great speed and when he swings back up, his flying show begins. He starts with a Cassina: in free fall, he performs a full-twisting double straight somersault. To do this, he first stretches out vertically in the air with his feet 40 centimetres above the bar. In the very next swing, he performs a Kovacs, a double tucked somersault in the air.

Epke grabs the bar, but he is not finished. After two rotations, *The Flying Dutchman* – as he is known – gives the most spectacular demonstration of his skill. He performs a combination of the Kolman (a double tucked somersault with a twist) followed by the Gaylord 2, a tricky angular somersault in which Epke grabs the bar facing backwards. It is a big risk. When this move works, the audience cheers. The dismount also goes perfectly and Epke lands solidly on the thick mat. He is laughing as he knows he is going to win. The jury is astonished and gives him 15.266 points, a higher score than he got in the world championships in 2018, when he also won gold. Today, Epke has become the European champion for the third time.

MEASURING FORCES

In addition to a busy life as an elite athlete, Epke also studied medicine in Groningen. He got his degree in 2018, twelve years after starting. Doctor Epke works one day a week in sports medicine in Heerenveen in Friesland. When he gets too old to continue as a gymnast on the horizontal bar, he will be able to make good use of his experience in his job as a sports doctor.

figure 1 Epke takes a risk with the Gaylord 2.

Epke himself has also been studied by various researchers. One is Bert Otten, professor of neuromechanics at the Centre of Human Movement Sciences, part of the University Medical Centre in Groningen. He is looking for the answer to the question: how can someone like Epke do what he does? Part of the question can be answered by a study of the forces that play a role in the moves on the horizontal bar. The gymnast does moves on the horizontal bar by using their muscle strength to start rotations. The gymnast can also control the bar's reaction force. You can use your knowledge of physics to get a better understanding of what is happening.

For his research, Bert Otten uses 3D movement recording systems that consist of multiple infrared cameras. Little reflective balls are attached to the gymnast's body. This lets you determine the position of the most important joints in the body during an exercise. Bert Otten can use that to determine the position of the centre of gravity for the various parts of the body.

However, this system can't be used during important competitions such as the Olympic Games. In such situations, Bert Otten uses high-resolution video cameras. Afterwards, he can calibrate the high-definition video images based on the dimensions of the horizontal bar, which are fixed by the rules of the sport. The international gymnastics federation says that the horizontal bar must be 240 cm long and have a diameter of 2.8 cm. The height is 278 cm. Using these numbers, a computer model can calculate the positions of the gymnast's joints. If you have two cameras from two different points of view, you are then able to reconstruct a three-dimensional image. This information can be used to determine the speeds, energies and forces at all times during the exercise.

figure 2 Two images from a recording of Epke Zonderland's movements during an exercise.

"The measurements and the model give you a better understanding of the exceptional aspect of the movements by very talented athletes like Epke Zonderland."

MODELLING FORCES

Epke's body length and weight are known and have been added to the computer model to make sure that the forces that are calculated are accurate. This was how Bert Otten found out that the forces exerted by Epke's hands can be very large. Just before his dismount, the force peaked at 4000 newtons, about the same as the weight of an old Fiat 500 without the seats.

That doesn't mean Epke can lift one of those cars on his own. When you lift something, the muscles become shorter and according to Bert Otten that makes them less powerful. However, when muscles become longer, as in the horizontal bar exercise, they become stronger and that is what Epke uses. The peak force only lasts 0.1 seconds. Biological tissues can cope well with brief periods of high loads; this does not cause permanent damage. And if you are Epke Zonderland, that means you can take such huge forces.

PRACTICE, DRIVE AND DISCIPLINE

The forces that Bert Otten measures during Epke's exercises are not always so extreme. Epke must not tense his muscles to the maximum either because his nervous system would then not be able to control the forces during the exercise.
Anyway, his muscles are not a very reliable 'engine' as they become tired and then need more control from the nervous system to achieve the same result. The only way to solve that problem is to practise a great deal.

Epke has also wondered how it is possible that he is able to perform so well on the horizontal bar. He says, "You can't do this without natural talent, discipline and living as an elite athlete. You have to train a lot and well every day. That's the only way that you can be the best. And of course you need to have the drive to be a champion." His advice is, "Do what you enjoy and what you are particularly good at."

Epke Zonderland

- date of birth: 16 April 1986
- height: 1.73 m
- weight: 69 kg
- specialist in: horizontal bar
- best results:
  Olympic gold in 2012
  world champion in 2018, 2014, 2013
  European champion in 2019, 2014, 2011

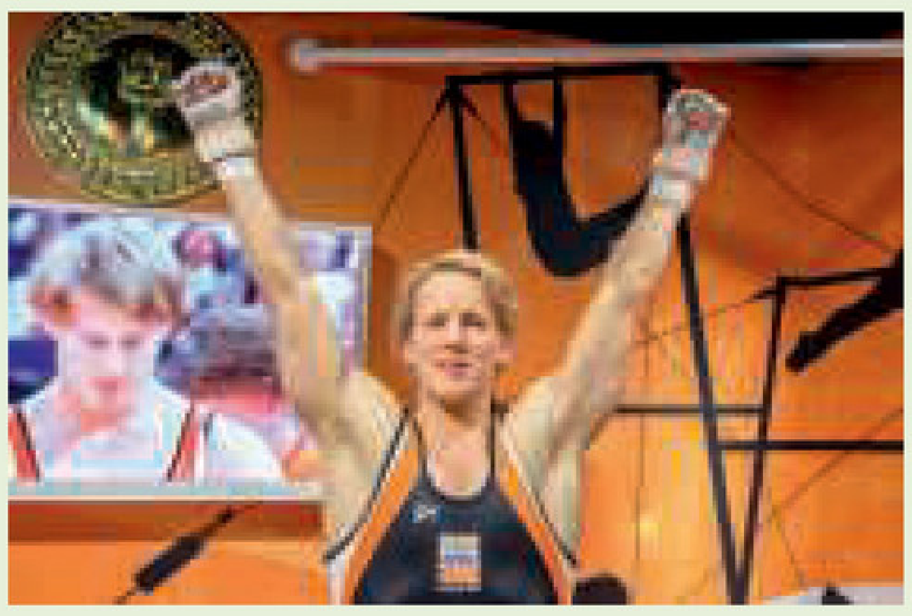


figure 3 Wax model of Epke Zonderland in Madame Tussauds in Amsterdam.

EXERCISES

1 A scientific article about the forces that occur in Epke's discipline states that the horizontal bar should behave like a spring according to the norms of the international gymnastics federation.

a Figure 4 shows a snapshot of the exercise in which Epke Zonderland became Olympic champion in 2012.
Use the data in figure 3 to calculate the force due to gravity acting on Epke in figure 4.

b In figure 4, draw in the forces due to gravity and the springiness of the horizontal bar. Use a force scale of $1\ \text{cm} \triangleq 400\ \text{N}$.

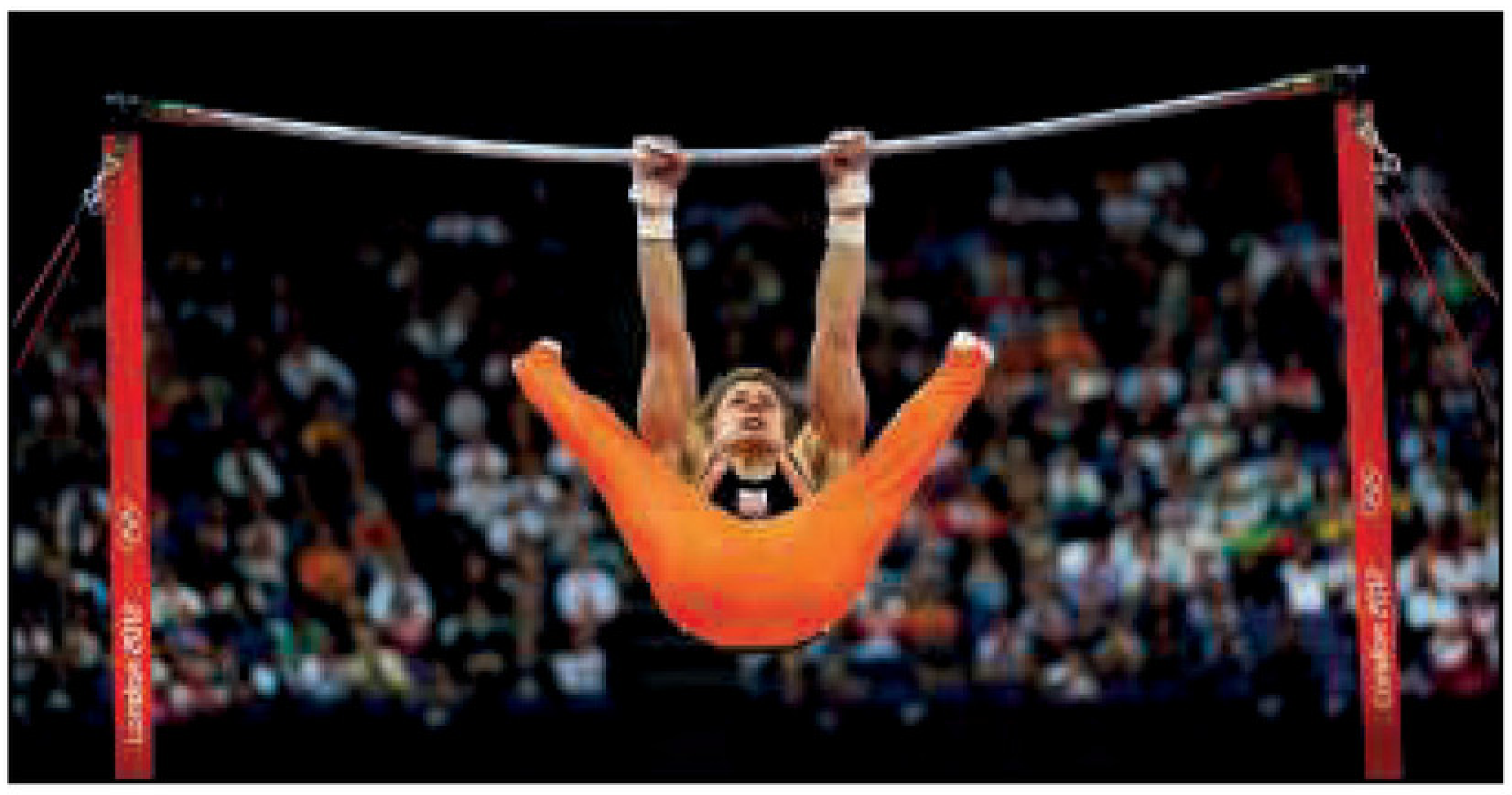


figure 4 Epke Zonderland doing the exercise with which he became Olympic champion in 2012.

c Use figure 4 and the data about the horizontal bar to determine how far the bar bends downwards in reality.

d Use your answers to exercises (a) and (c) to make an estimate of the bar's spring constant.

2 In the last swing before he starts 'flying', Epke gives a pull on the bar.

a Explain what benefit Epke gets from that pull on the bar.

b What is Epke's weight just after he lets go of the horizontal bar?

c Epke wears leather straps on his hands for the horizontal bar, as you can see in figure 4. Work out what forces could be influenced by these leather straps. You can also look up the answer on the Internet if you wish.

3 Find a video on the Internet of Epke Zonderland's performance on the horizontal bar at the 2019 World Cup in Baku.

a Measure the time it took Epke to complete a rotation of the horizontal bar without any special moves. Do this for three different rotations and calculate the mean (the average).

b When Epke is hanging straight from the horizontal bar, the distance from his hands to his toes is equal to 1.25× his height.
Calculate the circumference of the circle that Epke makes in a complete rotation around the horizontal bar.

c What is the average speed of Epke's toes during a complete rotation around the bar?

d When rotating round the bar, Epke exerts a force on the bar that acts as a centripetal force. This force is described by the formula

$$F = \frac{m\,v^2}{r}$$

Calculate this force. To do so, use the average speed of Epke's toes during a complete rotation. (In reality, the speed varies: it is faster than the average as Epke swings under the bar and slower than the average as Epke swings over the bar.)

Course material overview

2.1 TYPES OF FORCES

REMEMBER

- If a force is exerted on an object, the motion or the shape of that object will change. This deformation can be elastic or plastic.
- Muscle strength, elasticity, gravity, magnetic force and tensile force are examples of forces.
- You can measure forces with a dynamometer.
- You draw a force as an arrow with a starting point, a direction and a length.
- You calculate the force exerted by gravity on an object using the formula $F_g = m \cdot g$, where g is approximately 9.8 N/kg on Earth.
- All the small forces exerted by gravity on the parts of an object have the same effect as one big gravitational force acting on the centre of gravity.

CONCEPTS

centre of gravity
An imaginary point where you can imagine gravity as being applied to an object.

dynamometer
An instrument with a helical spring that is used to measure forces.

elastic deformation
Deformation in which the object regains its original shape once the force is no longer being exerted.

force
Concept in physics that makes clear how objects change one another's shape and/or motion.

force scale
Ratio that you use to draw forces. Shows the size of a force that is indicated by an arrow of 1 cm.

gravity
The force with which the Earth attracts you and all the objects around you.

magnetic force
A force that acts between the two poles of a magnet. It can be an attraction or repulsion.

muscle strength
A force that arises when the muscles in a body contract.

plastic deformation
Deformation in which the object remains deformed after a force has been exerted on it.

resilience
A force that arises when you extend or compress a springy material.

tensile force, tension
A force that arises in a rope if it is pulled at both ends.

vector
Way of representing the size, direction and point of application of a force as an arrow.

2.2 MORE THAN ONE FORCE

REMEMBER

- If the forces acting on an object are at rest or in equilibrium, nothing happens to that object.
- You calculate the spring constant of a constant with the formula $C = \frac{F}{x}$
- If the forces are acting along the same line, you can calculate the resultant by adding the forces together, with forces in one direction as positive numbers and forces in the opposite direction as negative numbers.
- Forces that act in different directions can be added using the parallelogram method. Because forces are vectors, you can't add them up like numbers.

CONCEPTS

directly proportional
Two variables are directly proportional if they increase or decrease in a fixed ratio: if the one variable increases or decreases *n*×, the other variable also increases or decreases *n*×.

extension
The increase in the length of a spring when a force is exerted on it.

normal force
A force that acts perpendicularly to the object's surface. An example is the force a tabletop exerts on a fruit bowl.

parallelogram method
Method for finding the resultant when two forces have some arbitrary angle between them.

resultant
The sum of the forces acting on an object. The forces have to be added as vectors, not as numbers.

spring constant
Property of a spring that indicates how far the spring extends when a force is exerted on it.

zero position
The length of a spring that has not been extended.

2.3 DRIVING FORCES AND RESISTING FORCES

REMEMBER

- There are three resistive forces that act against motion: air resistance (drag), sliding resistance (friction) and rolling resistance.
- You can reduce drag by reducing the frontal cross-section. You can reduce rolling resistance by pumping up the tyres of your bicycle.
- Newton's First Law says that if the resultant of all the forces is 0 N, then the object is either stationary or it moves along a straight line at a constant speed.
- If the direction of the resultant is the same as the direction of motion, the object accelerates.
- If the direction of the resultant is the opposite of the direction of motion, the object decelerates.
- If the direction of the resultant is perpendicular to the direction of motion, only the direction of the motion changes.
- If the resultant is at an angle but not perpendicular to the direction of motion, then both the speed and the direction of motion will change.

CONCEPTS

air resistance
Resistance that arises because a moving object has to push the air in front of it aside.

friction
Resistance that arises when two surfaces move against one another, such as a ski gliding over snow.

frontal cross-section
The surface of an object or person as seen from in front.

Newton's First Law
An object for which the resultant is 0 N is either stationary or it moves along a straight line with a constant speed.

resistance
A force that resists a motion and acts against that motion.

rolling resistance
Resistance that arises when a rolling object and the ground both become deformed during the motion.

2.4 FORCES IN THE UNIVERSE

REMEMBER

- There are eight planets in our solar system. The distances in the solar system are enormous. The planets go around the sun in elliptical orbits that are almost circular. It takes the Earth nearly 24 hours to rotate around its axis and one year to go round the sun.
- Isaac Newton realized that the sun's gravity is the reason for the planets' elliptical orbits around the sun.
- In any form of circular motion, there is a centripetal force that keeps making the object deviate from a straight line.
- The force you exert on the ground is called your weight. If you are not being held back by the ground or some other force acting upwards, you are in free fall. You are weightless when in a free fall.

CONCEPTS

centripetal force
Force pointing towards the centre of a circular or elliptical motion in which the moving object is constantly deviating and travelling in an orbit around the centre.

focus / foci
The foci are the two points, A and B, that you need in order to draw an ellipse. For all points P on the ellipse, the sum of the distances AP and BP is the same:
AP + BP = constant

free fall
State of an object where the only force acting on it is gravity. A free fall can be very brief (if you jump off something) or it can be endless (if you are travelling in a space station in an orbit around the Earth).

weight
The force that an object exerts on whatever it is resting on as a result of the force of gravity acting on the object.

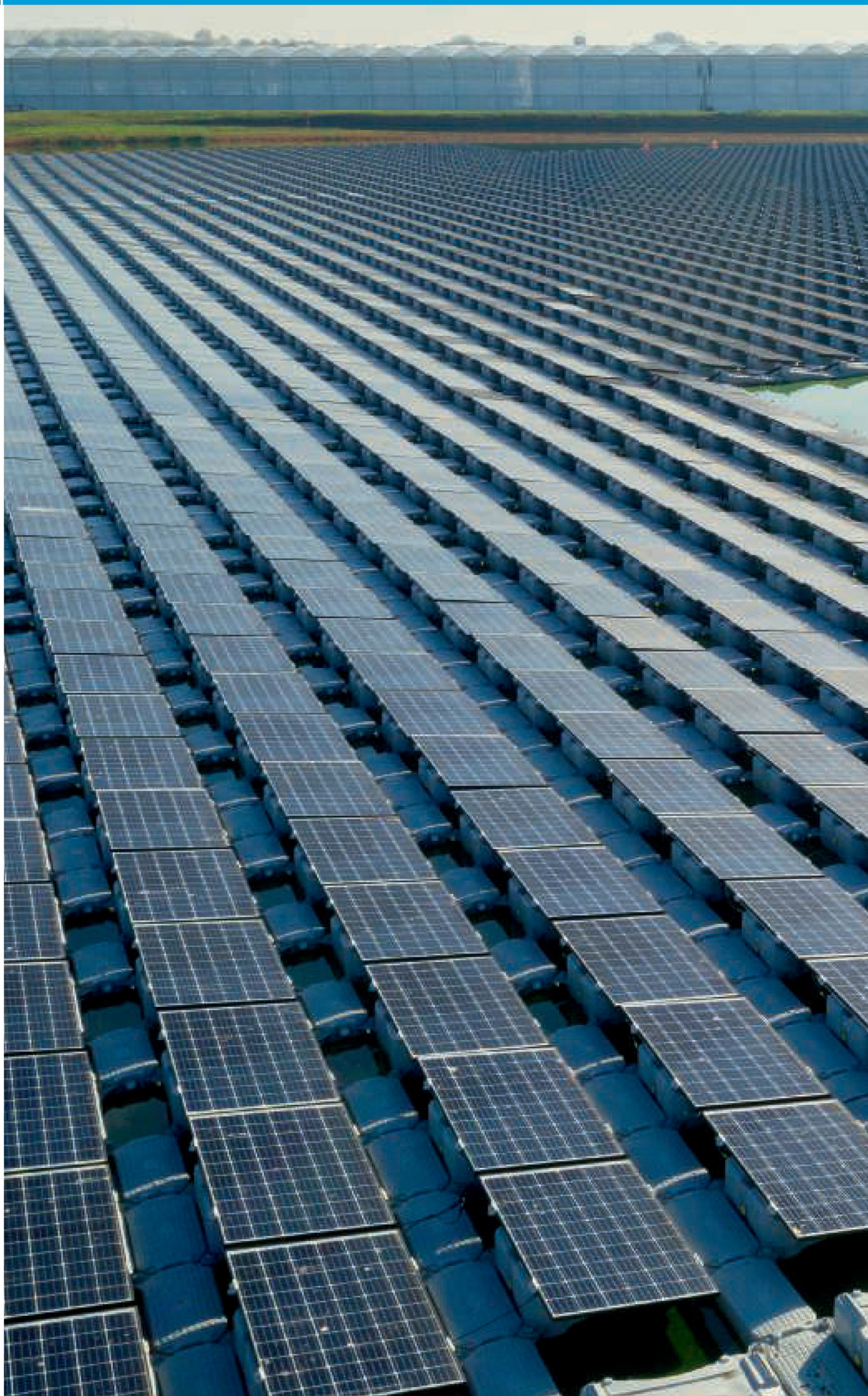
weightless
State in which an object has no weight because it is not resting on anything or suspended from anything.

Go to the *Flash cards* and the *Diagnostic test*.

3 Energy

SUSTAINABLE ENERGY SOURCES

People want to live comfortably. The energy needed for that is coming more and more frequently from renewable energy sources such as solar panels. At the same time, people also want their energy bills to be as low as possible. This is not only good for the environment but it also saves money.



What do you already know about energy?

LEARNING OBJECTIVES

1 You can explain what the Celsius scale is and what the measurement range of a thermometer is.
2 You can convert between energy units.
3 You can explain why air is a thermal insulator.
4 You can explain why a device with a higher power rating uses more electrical energy.
5 You can do calculations using the relationship between power, voltage and current.
6 You can calculate the electrical energy that was converted over a given time interval.

In Parts 1 and 2 of Nova NaSk and in Chapter 1 of this book, you learned a few things about energy and heat. You will need this knowledge when you start this chapter. If you want a quick check of what you can remember, do the following exercises.

EXERCISES TESTING YOUR PRIOR KNOWLEDGE

1 Have a look at figure 1.
Write down the measurement range of each thermometer.

a ....

b ....

c ....

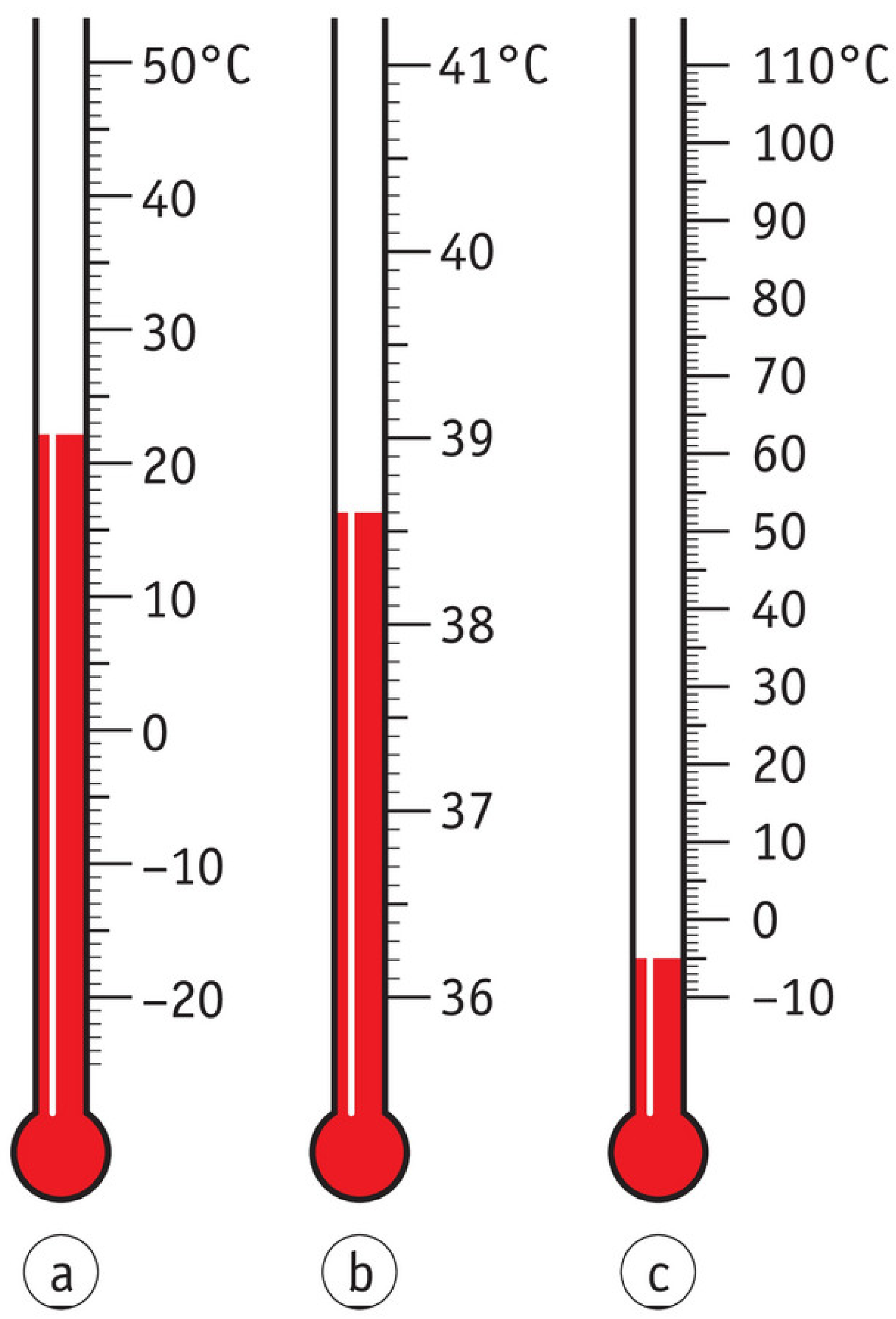


figure 1 Three thermometers.

2 Write down the temperature indicated by each thermometer.

a ....

b ....

c ....

3 If you want to make a graduated scale on a liquid thermometer, you mark the

temperature of .... as the zero point. This temperature

is .... °C. For the upper point of the graduated scale, you take the

temperature of .... That temperature is .... °C.

4 Convert.

22 kW = ...$\cdot 10^4$ W 0.060 kW = ... W

17 MW = ...$\cdot 10^4$ kW $3.25\cdot 10^7$ W = ... MW

5 Underline the materials that are good thermal insulators.

aluminium – down (feathers) – wood – iron – copper – polystyrene

6 You are mixing a smoothie using a blender. At that moment, a current of 2.17 A is going through the blender. The blender is connected to a socket via a plug.
Work out the power of the blender.

....

....

....

7 Jeremy's father has asked him to hoover the living room. This takes him 15 minutes. The power rating of the vacuum cleaner is 600 W.
Calculate how much energy (in kWh) the vacuum cleaner has consumed during that time.

....

....

....

If you want to know whether you have enough prior knowledge for this chapter, you can take the online *Prior knowledge test*. You can also find videos about the key learning objectives for this chapter there.

1 Energy sources

LEARNING OBJECTIVES

3.1.1 You can explain what an energy source is.
3.1.2 You can list six energy sources.
3.1.3 You can write down the characteristics of energy sources.
3.1.4 You can describe an ideal energy source.
3.1.5 You can write down four characteristics of the energy transition.
PLUS 3.1.6 You can do calculations involving speed and power.

There is a great deal of discussion about energy sources in the Netherlands. The government wants to greatly reduce the use of natural gas. Renewable energy sources such as wind and solar power must get a larger share. Not everyone agrees with this, because every energy source has disadvantages as well as advantages.

WHAT IS AN ENERGY SOURCE?

Anything that can provide a usable form of energy is called an **energy source**. Sometimes you use that energy directly, such as when you let the sun heat your house, but usually you use a device that converts the energy form of the source into another form of energy:

- A solar cell converts the radiant energy of sunlight into electrical energy.
- A wind turbine converts the kinetic energy of flowing air into electrical energy.
- A stove converts the chemical energy of natural gas into heat.

Sunlight, wind and natural gas are examples of energy sources: they deliver a usable form of energy.

ENERGY SOURCES

Six energy sources that are used in the Netherlands are listed below. After each energy source, it states the contribution that source made to overall energy use in the Netherlands in 2018 (source: www.cbs.nl).

Fossil fuels (91.4%)

Fossil fuels such as petroleum, natural gas and coal provide **chemical energy**. Petroleum products are used in transport on a large scale. Natural gas is used to heat buildings and in power stations. Several power stations in the Netherlands use coal (figure 1).

figure 1 A coal-fired power station in the Eemshaven in northern Groningen.

Biomass (4.5%)
Biomass is material originating from plants and animals. This can for instance be prunings and waste wood, plant remains and manure, as well as crops such as rapeseed and maize. Biomass provides chemical energy. Some types of biomass can be burned directly. Manure can be fermented in a biogas plant. This produces a gaseous product: biogas. The composition of biogas is very similar to natural gas and it can be used for the same purposes.

Wind (1.7%)
Wind as an energy source is becoming increasingly important. You see more and more wind turbines in the landscape. The blades of such a windmill or **wind turbine** drive a generator that is built into it. This converts the **kinetic energy** of wind into electrical energy.

Nuclear fission (1.4%)
Some atomic nuclei, such as uranium nuclei, can be split. Splitting an atomic nucleus like this releases a lot of energy in the form of heat. In a nuclear power station, this heat is used to make steam. The steam is forced at high speed past the blades of a turbine that is connected to a generator. The generator converts that kinetic energy into electrical energy.

Solar (0.6%)
The sun is a source of **radiant energy**. A **solar collector** converts the radiant energy of the sun into heat that is used to heat water (figure 2). **Solar cells** convert irradiation into electrical energy. More and more people are getting panels with solar cells installed on the roof of their house or shed (figure 3).

figure 2 Solar collectors provide hot water.

figure 3 This is how solar panels are fitted.

Geothermal heat (0.2%)

The deeper you go in the ground, the higher the temperature. It is possible to bring heat from the deep layers of the ground up to the surface. Two wells are used to extract this **geothermal heat** (figure 4). The first well is used for pumping hot groundwater up from the depths. This groundwater can be contaminated and contain salts. The hot groundwater is passed through a **heat exchanger** where it transfers part of its heat to cold water. The second well is then used for pumping the groundwater back into the ground.

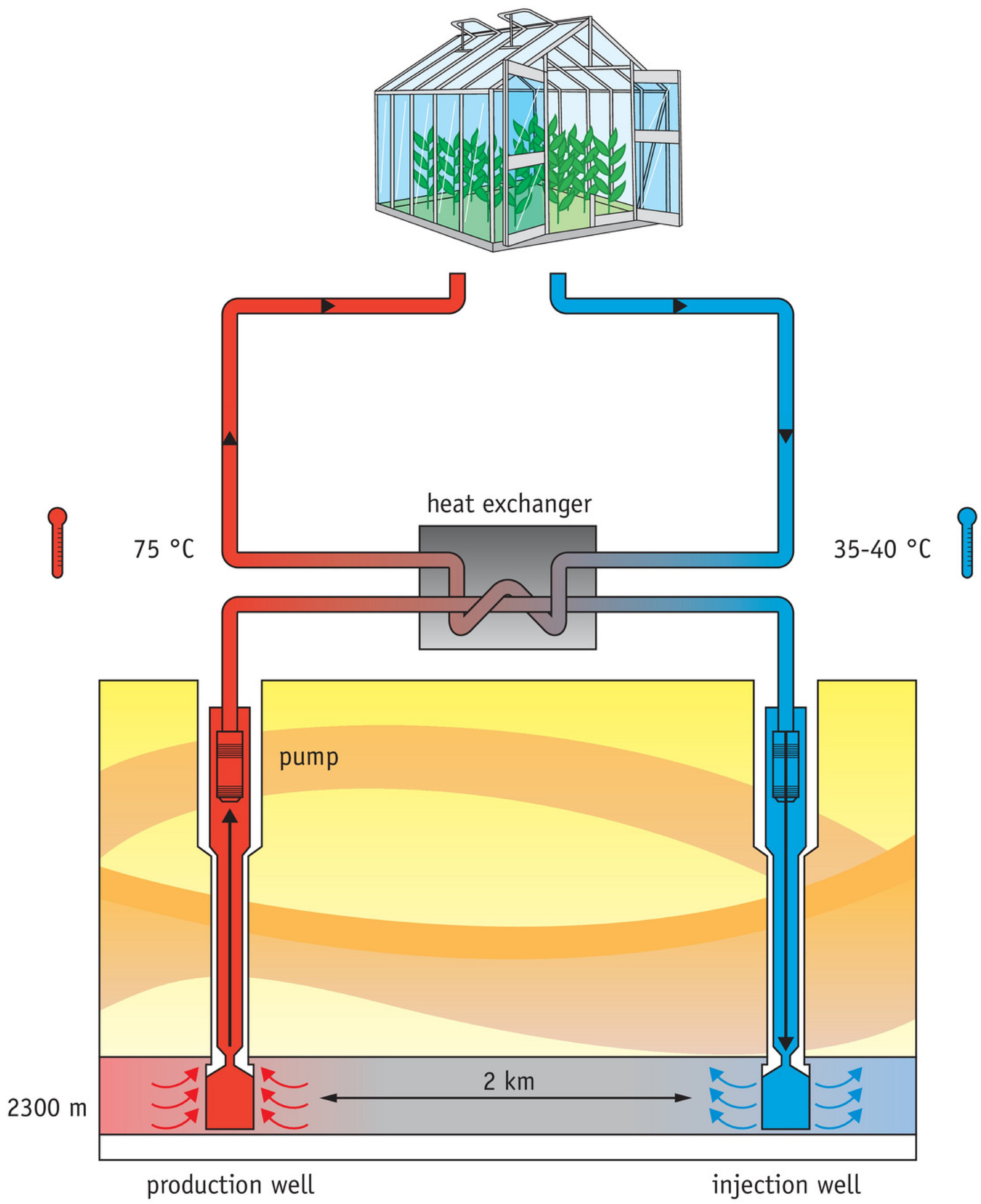


figure 4 Geothermal heat can be used for heating greenhouses, for example.

THE ENERGY TRANSITION

The ideal energy source is inexhaustible, always available, environmentally friendly and cheap. But ideal energy sources don't exist. Fossil fuels are not inexhaustible. Wind and sun are not always available. Whatever type of energy source you use, there are always high costs and disadvantages for the environment.

Natural gas was first seen as an ideal energy source because only water vapour and carbon dioxide are produced when natural gas is burned. Carbon dioxide is odourless and not toxic and was therefore considered harmless. It wasn't until later that people realized carbon dioxide is a harmful greenhouse gas and poses a threat to the climate.

Now it is mainly the disadvantages of natural gas that are emphasized. The Dutch government wants to 'get rid of gas' and switch to other, 'climate-neutral' energy sources as quickly as possible. This is referred to as the **energy transition**. A new energy system needs to be created with the following four characteristics:

Sustainable energy sources

Fossil fuels must have almost completely been replaced by renewable energy sources such as wind and solar power. Power stations must be shut down or made to run on biomass and most vehicles must have electric engines. Houses must be heated by heat pumps or geothermal heat or waste heat from industry.

Efficient energy management

The use of energy must be limited as much as possible. Buildings are well insulated and appliances are efficient, such as LED lights and energy-efficient vacuum cleaners and refrigerators. People need to be aware that they must use energy economically, for example by taking less time to shower and not leaving devices in standby mode.

Large-scale energy storage

There are possibilities for storing large quantities of energy efficiently. Wind and sun are not always available as energy sources, after all. Examples are storage in large batteries or in the form of hydrogen gas.

Local production of energy

Energy supplies have to be arranged more locally (figure 5). For example, energy is generated by solar panels on the roofs of buildings and by small wind farms throughout the country. Large power stations are less important.

figure 5 This solar farm generates electrical energy for local use.

PLUS THE POWER OF A WIND TURBINE

The average wind speed in the Netherlands is quite high because it is near the North Sea. This makes it suitable for generating electrical energy with wind turbines. Figure 6 shows the average wind speeds. The lines in this diagram connect places with the same average wind speed.

In 2019, there were four Dutch wind farms in the North Sea with a combined capacity of approximately 1000 MW. This is roughly the electricity requirement of three million households. There are plans to expand that to 4000 MW in the coming years.
There are different requirements for wind turbines at sea than for wind turbines on land. Wind turbines at sea are taller and they have bigger blades (figure 7).

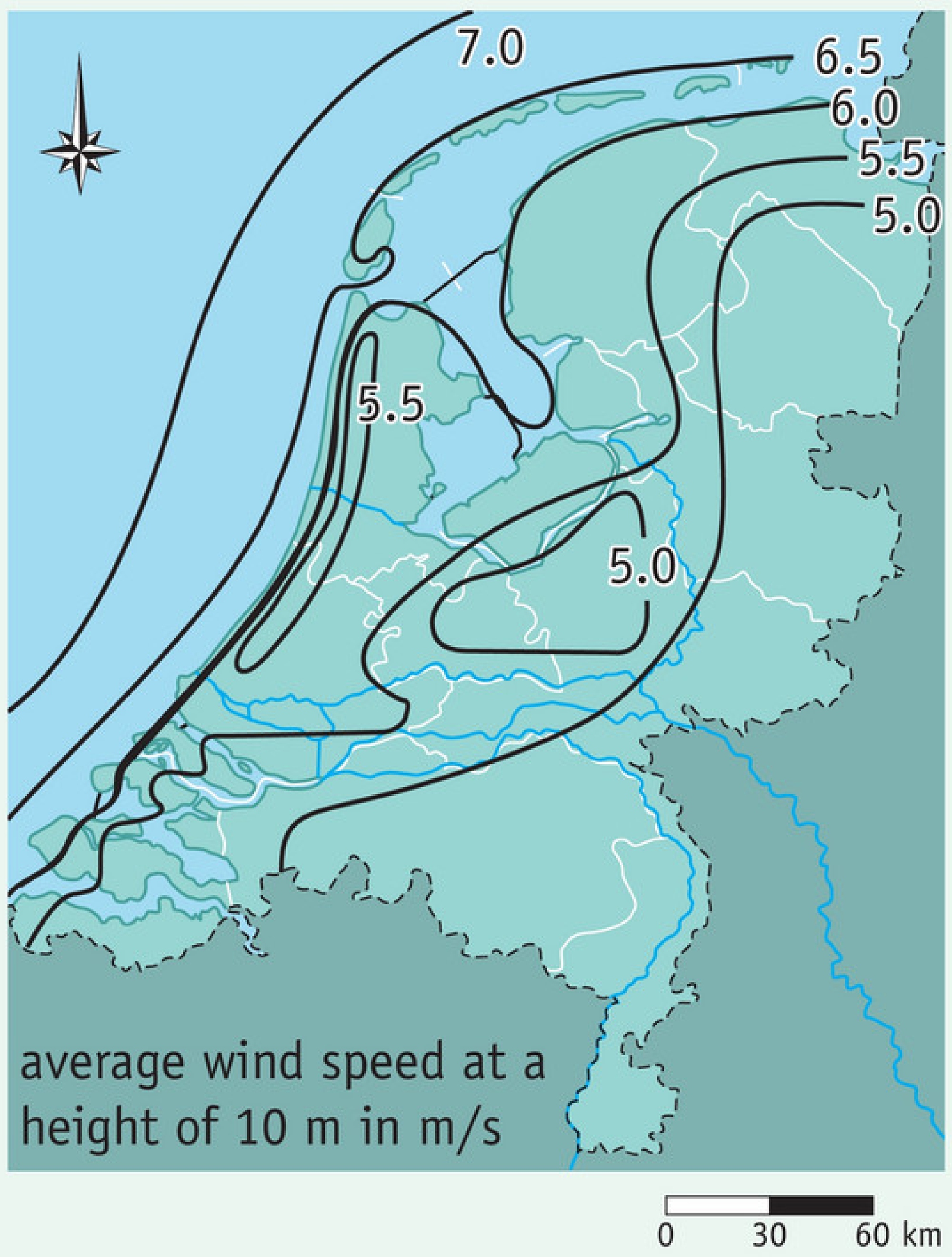


figure 6 This shows how much wind there is on average in the Netherlands.

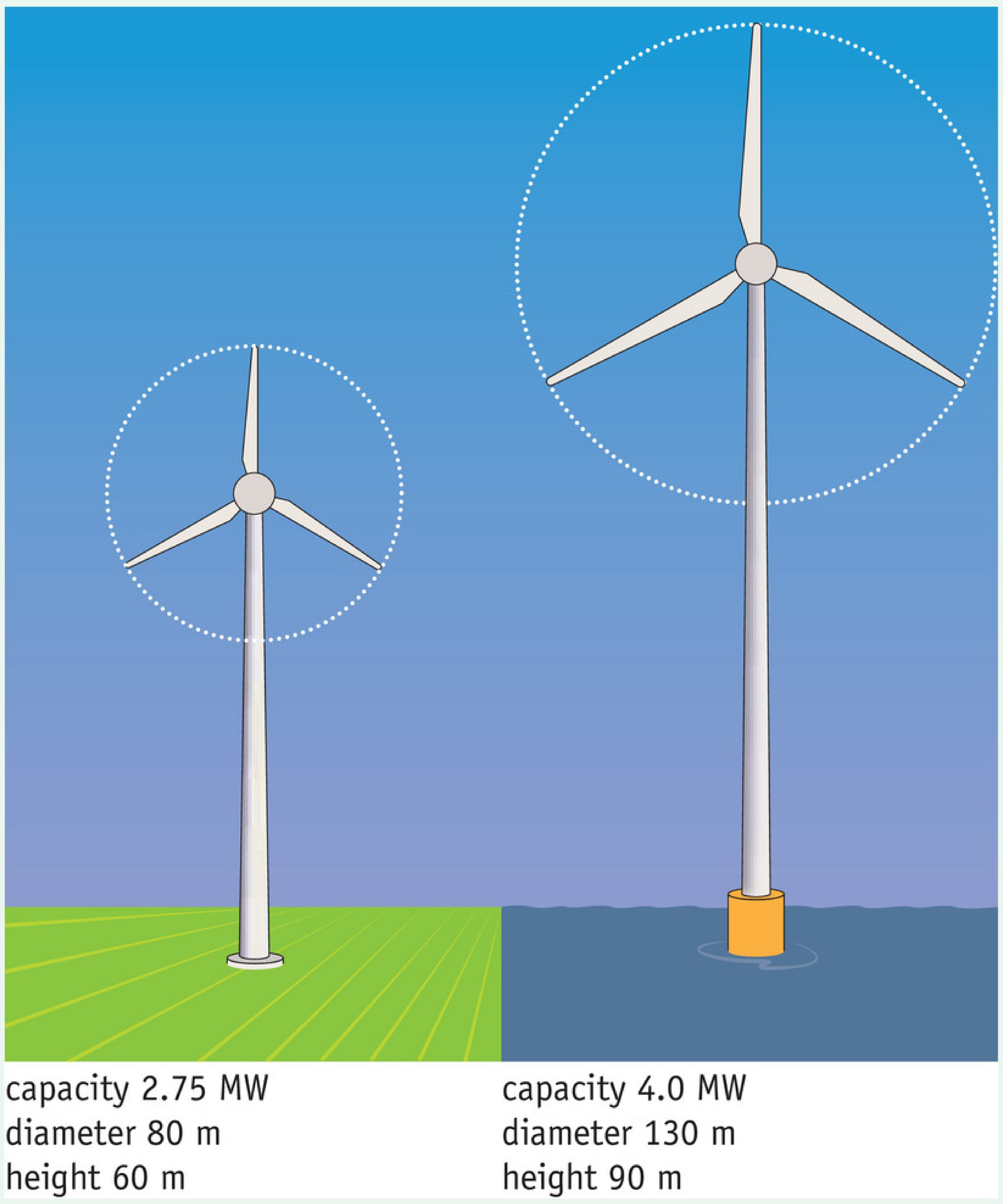


figure 7 Wind turbines on land and at sea.

The power of a wind turbine, or the amount of electrical energy it generates per second, can be calculated as follows:

$$P = k \cdot v^3$$

where:
- P is the power in W;
- k is a constant that depends on things such as the diameter of the blades and the density of the air that flows around them;
- v is the wind speed in m/s.

EXAMPLE EXERCISE 1

There are strong winds at the Gemini wind farm, north of the island of Ameland. In the case of a wind turbine in that farm, $k = 2.3 \cdot 10^3$. The wind turbine is generating 3.1 MW. Calculate the wind speed.

given $k = 2.3 \cdot 10^3$
$P = 3.1$ MW = 3,100,000 W

required $v = ?$ m/s

$$P = k \cdot v^3$$

$$v^3 = \frac{P}{k}$$

$$v = \sqrt[3]{\frac{P}{k}} = \sqrt[3]{\frac{3{,}100{,}000}{2300}} = 11.04\ldots$$

working $v = 11$ m/s

Practice the concepts using the *Flash cards*.

COURSE MATERIAL

1 Answer the following questions.

a Which three fossil fuels are widely used in the Netherlands?
b What energy conversion takes place in a wind turbine?
c What is the difference between a solar collector and a solar panel?
d What characteristics does an ideal energy source have?
e Which four characteristics will the energy transition provide for the energy system?
f What is meant by ‘producing energy locally’?

2 Complete the missing data.

table 1 Six sources of energy that are used in the Netherlands.

energy source	form of energy	energy converter
		central heating boiler
biomass		
Sun		
		heat exchanger
	kinetic energy	
	nuclear energy	

IN PRACTICE

3 Read the newspaper article in figure 8.

a The articles states that the solar oven spares the environment.
Explain what is being 'saved'.

b People in Africa often have to walk for hours to get wood as fuel. There is no more wood close to their villages.
Why might that be the case?

c The article mentions various advantages of the solar oven.
Think of a disadvantage of the solar oven too.

d The aluminium pan is put in a plastic bag that is loosely tied.
Why do you need to put a plastic bag around the pan?

The Cookit

The Cookit is a simple solar cooker. It is made of cardboard that is covered with a layer of aluminium foil. The food is put in a four-litre lightweight aluminium pan, painted matt black with blackboard paint. Three flat stones are put in a heat-resistant plastic bag and the pan is placed on top. This lets the heat circulate around the pan. The plastic bag is loosely tied with a piece of string. The whole thing is put out in the sun. Most dishes are ready after two to three hours. The quality is excellent. The oven is cheap and spares the environment. A family no longer has to spend hours every day collecting wood to burn. Each solar cooker saves twenty trees a year.

Source: solarcookingkozon.nl

figure 8 Solar energy for Africa.

★ 4 Placing solar panels along the motorways would let a large number of Dutch households be provided with electrical energy. An average household in the Netherlands uses 3500 kWh/year. A solar panel delivers 80 kWh/m^2 per year.

a Calculate the surface area of solar panelling needed for one household.

b The Netherlands has 2360 km of motorways. Suppose that solar panels 4.0 m tall are placed along both sides of all motorways.
Calculate how many households these solar panels could provide electrical energy for.

c Think of three possible disadvantages of this plan.

5 The supply of energy is not constant and that is why it is useful to build up a stockpile of energy.
Where and in what form is such a stock of energy stored:

a by an oil company that is taking an 'oil crisis' into account?

b by a potato plant that has a lot of energy 'left' after the summer?

c by a bear preparing in the autumn for the coming winter?

6 There are often strong winds in the Netherlands. The average wind speeds are shown in figure 6. The lines in this diagram connect places with the same average wind speed.

- **a** Explain why the average wind speed is lower inland than in the coastal regions.
- **b** The wind speed is the highest by the sea.
  Explain why wind turbines are not placed everywhere in the dunes.
- **c** Nowadays, wind turbines are also placed in the North Sea, 10 km or more from the coast.
  What advantages would that have? Write down two.
- **d** Also think of a disadvantage of placing wind turbines at sea.
- **e** One disadvantage of wind energy is that it is not always windy.
  How could you store the energy generated by wind turbines for use when it is not windy?

7 Assess the energy sources in table 2 in terms of sustainability for the distant future, round-the-clock availability and environmental friendliness: + is good, 0 is fair, − is bad.

table 2 Six energy sources and their characteristics.

energy source	sustainability	availability	environmental friendliness
petroleum			
biomass			
solar			
geothermal heat			
wind			
nuclear fission			

8 Hydrogen is a combustible gas that is suitable as fuel for industry and transport. You can make this gas by splitting water into hydrogen and oxygen using electricity.

- **a** What energy conversion takes place in this production process?
- **b** Explain how you can produce hydrogen sustainably.
- **c** Explain how hydrogen can help us achieve the energy transition.

9 Look on the Internet for more information about the following energy sources: natural gas, geothermal heat, biomass, tides, coal, wind, sun.
Describe in a schoolwork project of a maximum of two A4 pages:

- how the energy source can be used;
- what the advantages of the energy source are;
- what the disadvantages and limitations of the energy source are.

Test what you know with *Test yourself.*

PLUS THE POWER OF A WIND TURBINE

10 In figure 7, the constant for the wind turbine on land is $k = 8.8 \cdot 10^2$; for the wind turbine at sea, it is $k = 2.3 \cdot 10^3$.

a Use figure 6 to determine the power that a wind turbine on the Maasvlakte (on the coast near Rotterdam) delivers, based on the average wind speed there.

b The wind turbine on land can generate up to 2.75 MW.
Calculate the wind speed needed to achieve this power.

c The wind speed you found in Exercise (b) is much higher than the average wind speed. Apparently, the designers thought it was important that the wind turbine still works properly at this speed. The wind turbine is only stopped at even higher wind speeds because it would break otherwise.
Explain why it is important that the wind turbine works properly at wind speeds higher than average.

11

a Angie and Dylan wonder why the k value is different for wind turbines on land and at sea. They compare a wind turbine on land ($k = 8.8 \cdot 10^2$) with a wind turbine ($k = 2.3 \cdot 10^3$) at sea.
Calculate the factor by which the k value of the wind turbine is greater at sea than on land.

b Angie and Dylan each formulate a hypothesis:
Angie thinks that k is directly proportional to the diameter of the wind turbine.
Dylan thinks that k is directly proportional to the area of the circle swept out by the blades.
Use figure 7 to investigate which of the two hypotheses fits better.
Tip: to test Dylan's hypothesis, first calculate the area of the circle for both wind turbines and check how much bigger the circle of the wind turbine at sea is.

2 Heating

LEARNING OBJECTIVES

3.2.1 You can explain that the quantity (amount of energy) does not change in an energy conversion but the quality (usefulness) does.
3.2.2 You can show energy conversions in an energy flow diagram, taking account of the law of conservation of energy.
3.2.3 You can explain that heat needs to be added in order to raise the temperature of a substance.
3.2.4 You can calculate the amount of energy required to raise the temperature of a substance, using the specific heat capacity.
PLUS 3.2.5 You can use the particle model to explain and analyse evaporation and condensation.

People need heat to heat their homes, boil water and prepare food. They use heat sources for this such as central heating boilers, ovens, hot water boilers and boiling water taps. Most of these heat sources use electrical energy. Others use the chemical energy from natural gas.

HEAT SOURCES

If you look around at home, you will find various **heat sources**. A central heating boiler or heat pump supplies the heat that heats the house. Other heat sources are a cooker, an oven, an electric kettle, a soldering iron, a hairdryer and a tumble dryer.

An electric boiler has a heating element. An electric current passes through the heating element and that makes the heating element warm up. This turns **electrical energy** into **heat**. Such an **energy conversion** can be represented in an **energy flow diagram**, as shown in figure 1. The arrow on the left represents the energy that the heat source absorbs (uses). The arrow on the right represents the energy that the heat source releases (provides).

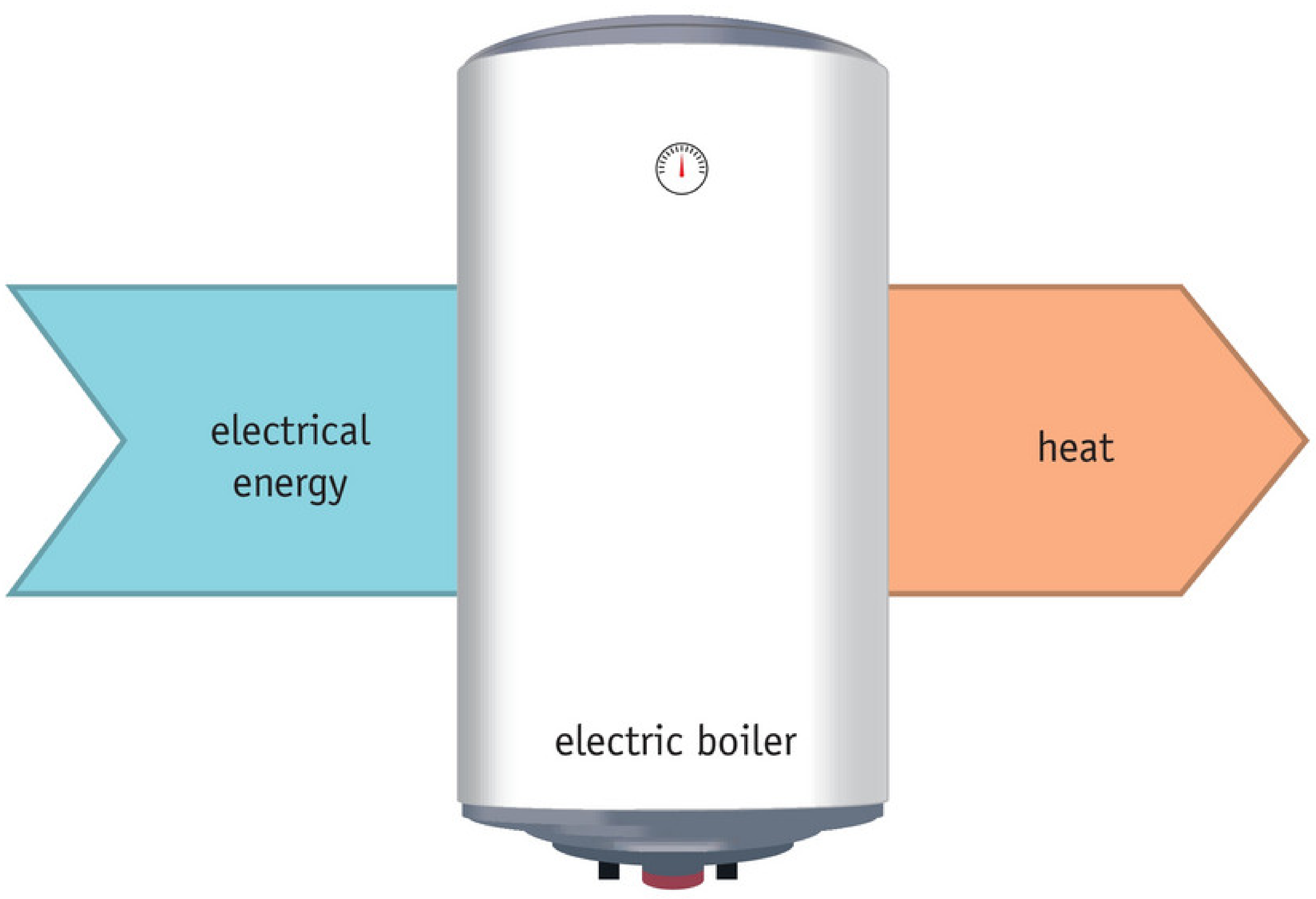


figure 1 The energy flow diagram for an electric boiler.

Scientists have discovered that the **amount** of energy never changes during an energy conversion. Certain types of energy disappear and other types of energy take their place, but the total amount of energy remains the same. This is called the **law of conservation of energy**. That's why the left and right arrows in an energy flow diagram are the same size: it shows that nothing gets added or subtracted from the total.

What does change is the **quality** of the energy. Electrical energy is a high-quality, concentrated form of energy that you can use to do all sorts of things. Heat is not, because this form of energy naturally spreads over the area. As a result, the quality of the energy is reduced: that energy still exists, but you cannot use it. When people speak of the threat of a shortage of energy, they mean a shortage of high-quality, concentrated energy.

HEAT AND TEMPERATURE

Most of the heat sources that you will find at home use electrical energy. Consider an electric kettle that you use to boil water for a cup of tea (figure 2). The electrical energy used by that heat source is completely converted into heat: every joule of electrical energy used gets you one joule of heat.

figure 2 Heating water for a cup of tea.

When you heat water in an electric kettle, the temperature of the water rise from about 20 °C to 100 °C in just a few minutes. Increasing the temperature means that the average speed of the water molecules increases. The temperature is therefore a measure of the average speed of the molecules of a substance. The heat absorbed by the water is used to make the water molecules move faster. The water molecules have more kinetic energy.

When water reaches a temperature of 100 °C, it starts to boil. The heat absorbed by the water is then used to move the water molecules away from each other. This creates bubbles of water vapour everywhere in the liquid. The temperature of the water will not increase anymore and stays at 100 °C. The electric kettle turns itself off at this point.

The more water you put in an electric kettle, the longer it takes before the water boils. This is because there are more water molecules whose average speed has to be increased. More heat (energy) is needed and that means the electric kettle – which has a constant power output – takes longer to do the heating.

EXPERIMENTS WITH A CALORIMETER

You can measure how much heat is required to heat a certain amount of water using a heat meter called a '**calorimeter**'. Figure 3 shows a cross-section of a calorimeter. The water in the beaker is heated up with a plunger: a heating element that converts electrical energy into heat. Because the beaker is well-insulated, almost all of the generated heat is absorbed by the water.

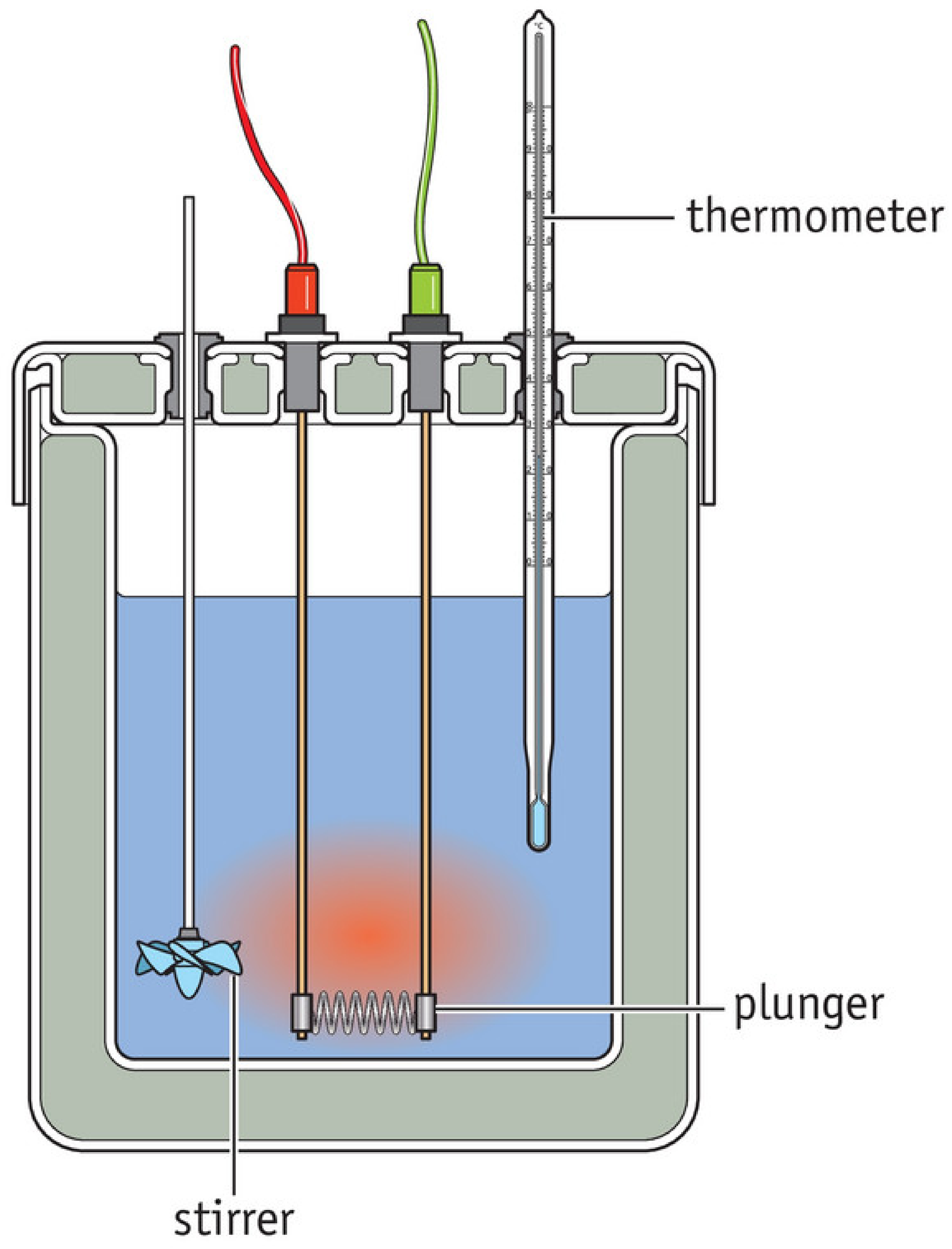


figure 3 Cross-section through a calorimeter.

EXAMPLE EXERCISE 1

Anouk fills the calorimeter with 100 g water and heats it with a plunger of 12 W (figure 4). After 12 minutes, the temperature of the water has increased from 19 °C to 39 °C.
Calculate how much heat the plunger generated.

given t = 12 min = 720 s
P = 12 W

required E = ?

working $E = P \cdot t = 12 \times 720 = 8640$ J = 8.6 kJ

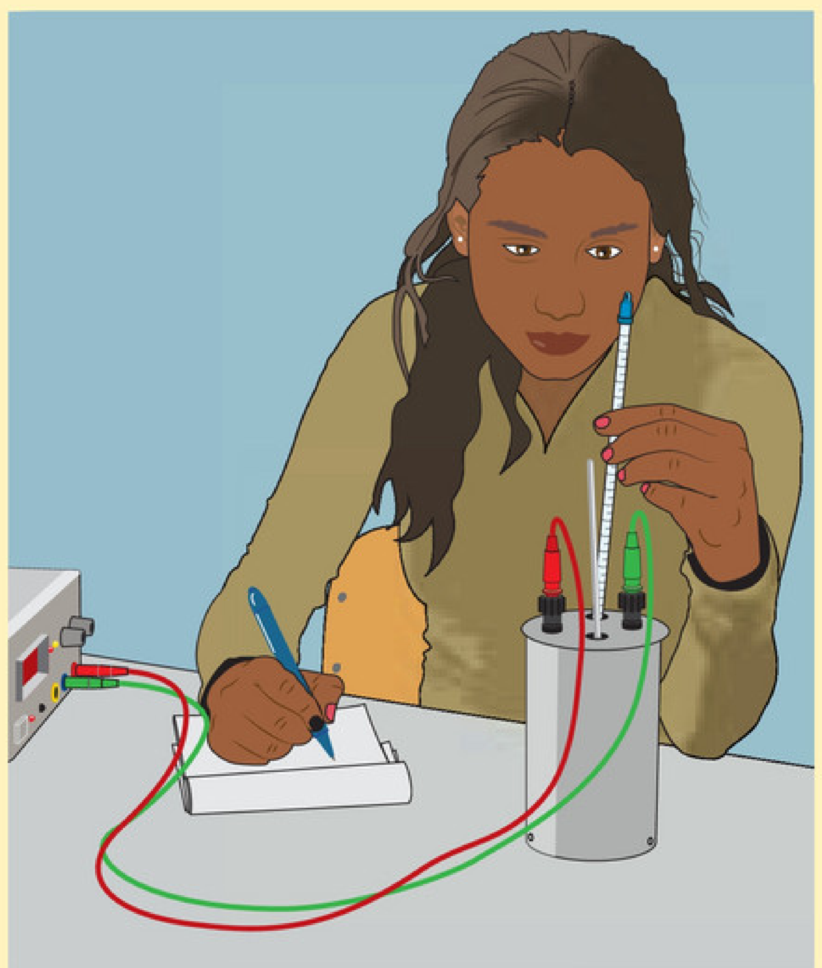


figure 4 Making measurements with a calorimeter.

In Example Exercise 1, 8.6 kJ was required to increase the temperature of the water by 20 °C. In reality, this value is a little bit too high because some of the heat leaks out. Precise experiments show that you need 4.2 J of heat to raise the temperature of 1 g water by 1 °C. It doesn't matter whether the temperature increase is from 11 °C to 12 °C, or from 78 °C to 79 °C (figure 5).

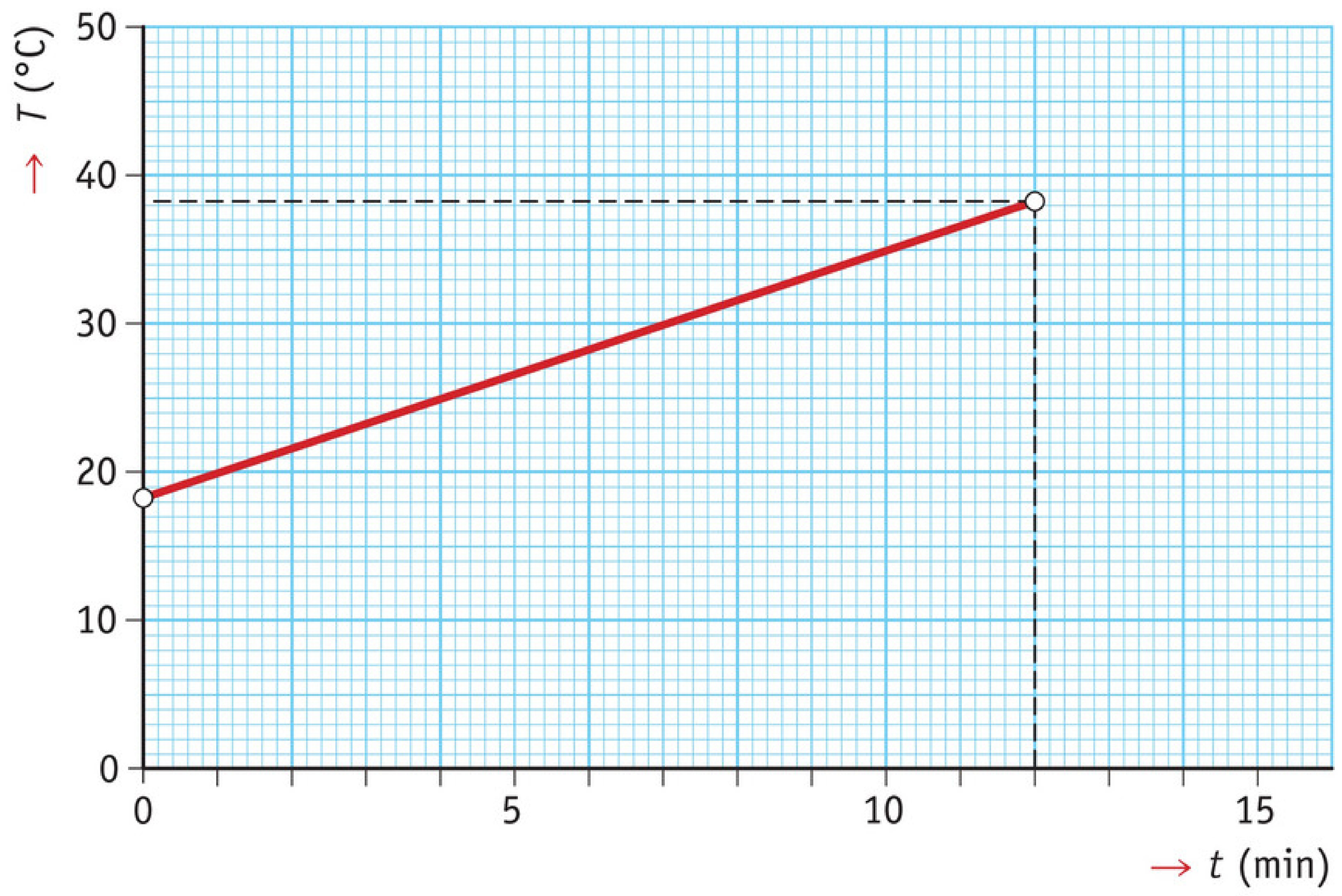


figure 5 The temperature increases steadily during heating: the same amount of heat is needed for each degree that the temperature rises.

The amount of heat required to increase the temperature of 1 g of any substance by 1 °C is called the **specific heat** of that substance. The specific heat of water is 4.2 J/(g·°C). The character c is used as the symbol for specific heat. You can also write the previous sentence like this: c_{water} = 4.2 J/(g·°C). The specific heat is a property of a substance: every substance has its own specific heat.

CALCULATIONS WITH SPECIFIC HEAT

EXP. 1

It often happens that you want to heat a certain substance to a given temperature. You can calculate the amount of heat required using a formula. You multiply the specific heat of the substance by the mass of the substance and the increase in temperature.

$$Q = c \cdot m \cdot \Delta T$$

where:

- Q is the heat in joules (J);
- c is the specific heat in joules per gram per degree Celsius (J/(g·°C));
- m is the quantity of a substance in grams (g);
- $\Delta T = T_{end} - T_{start}$, the desired temperature increase in degrees Celsius (°C).

This formula uses the mass as the measure for an amount of liquid. This is done because the volume of the liquid increases when it is heated, whereas the mass remains constant. In addition, the mass is easier to measure. In calculations, you can assume that 1.0 L water equals $1.0 \cdot 10^3$ g.

EXAMPLE EXERCISE 2

A boiling water tap heats 1.5 L water from 20 °C to 100 °C.
Calculate how much electrical energy the boiling water tap has to convert. Assume that all the electrical energy is used to heat the water.

The mass of 1.5 L water is $1.5 \cdot 10^3$ g.

given	c = 4.2 J/(g·°C)
	$m = 1.5 \cdot 10^3$ g
	$\Delta T = T_{end} - T_{start} = 100 - 20 = 80$ °C
required	Q= ?
working	$Q = c \cdot m \cdot \Delta T = 4.2 \times 1.5 \cdot 10^3 \times 80 = 5.04 \cdot 10^5$ J = 504 kJ

PLUS THE HEAT PUMP

A car engine is cooled with water. The temperature of the engine will be much higher than the temperature of the coolant water. Heat 'spontaneously' flows from the hot engine to the cold water.

A heat pump is a device that can do the opposite: make heat go from a place with a low temperature to an environment with a higher temperature. Refrigerators and air conditioning units have heat pumps, for example.

Figure 6 shows a schematic diagram of a heat pump that heats a house in the winter. The tubes contain a liquid such as ammonia, which has a very low boiling point. The ammonia can evaporate in the tubing system outdoors, absorbing heat from the outside air as it does so. The effect of that energy is that it increases the distance between the ammonia molecules (which attract each other according to the particle model). A compressor pumps the refrigerant round and compresses the ammonia vapour, which then condenses. This releases the heat that the ammonia absorbed outside. You can use that heat to heat your room. After passing the expansion valve, the ammonia will have cooled down sufficiently for a new round through the tubing system.
In the summer you can use the pump to cool your house by reversing the entire process.

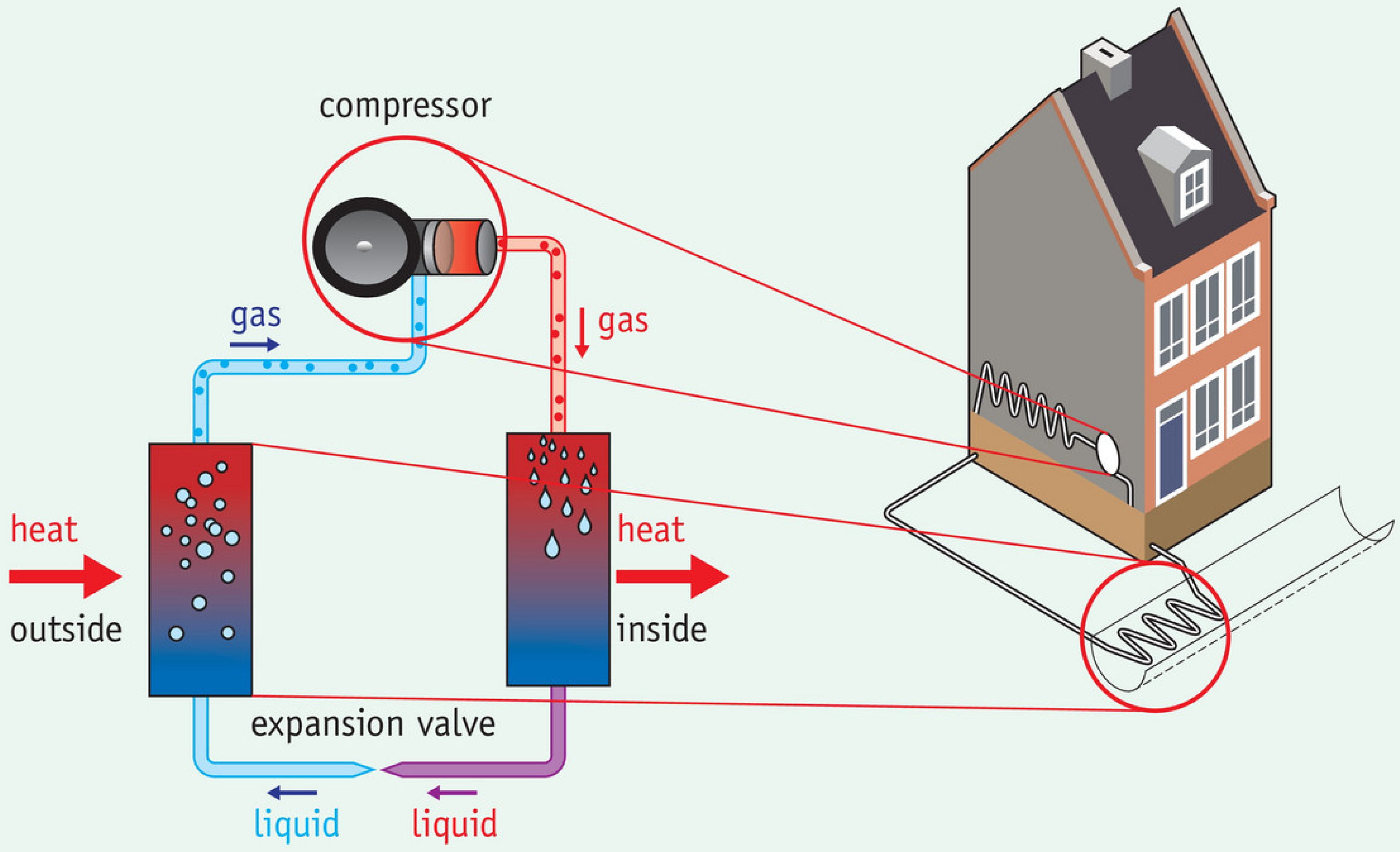


figure 6 This is how a heat pump works.

Practice the concepts using the *Flash cards*.

COURSE MATERIAL

1 Answer the following questions.

a What energy conversion takes place in a gas central heating boiler?
b Why are the left and right arrows in an energy flow diagram the same size?
c Why is heat less valuable than chemical energy, for example?
d What happens to water molecules when the temperature of water increases?
e What does “the specific heat of water is 4.2 J/(g·°C)” mean?

2 Look at the illustration of the calorimeter in figure 3.

a How does the water in this calorimeter get heated up?
b How can you prevent heat from leaking from the calorimeter unnecessarily?
c Why do you have to keep stirring while heating?

IN PRACTICE

3 A power station burns natural gas and produces electrical energy. That process releases a lot of heat. Only 40% of the energy supplied is converted into useful energy.

a Complete the energy flow diagram in figure 7.
b Write the names of the forms of energy in the arrows.

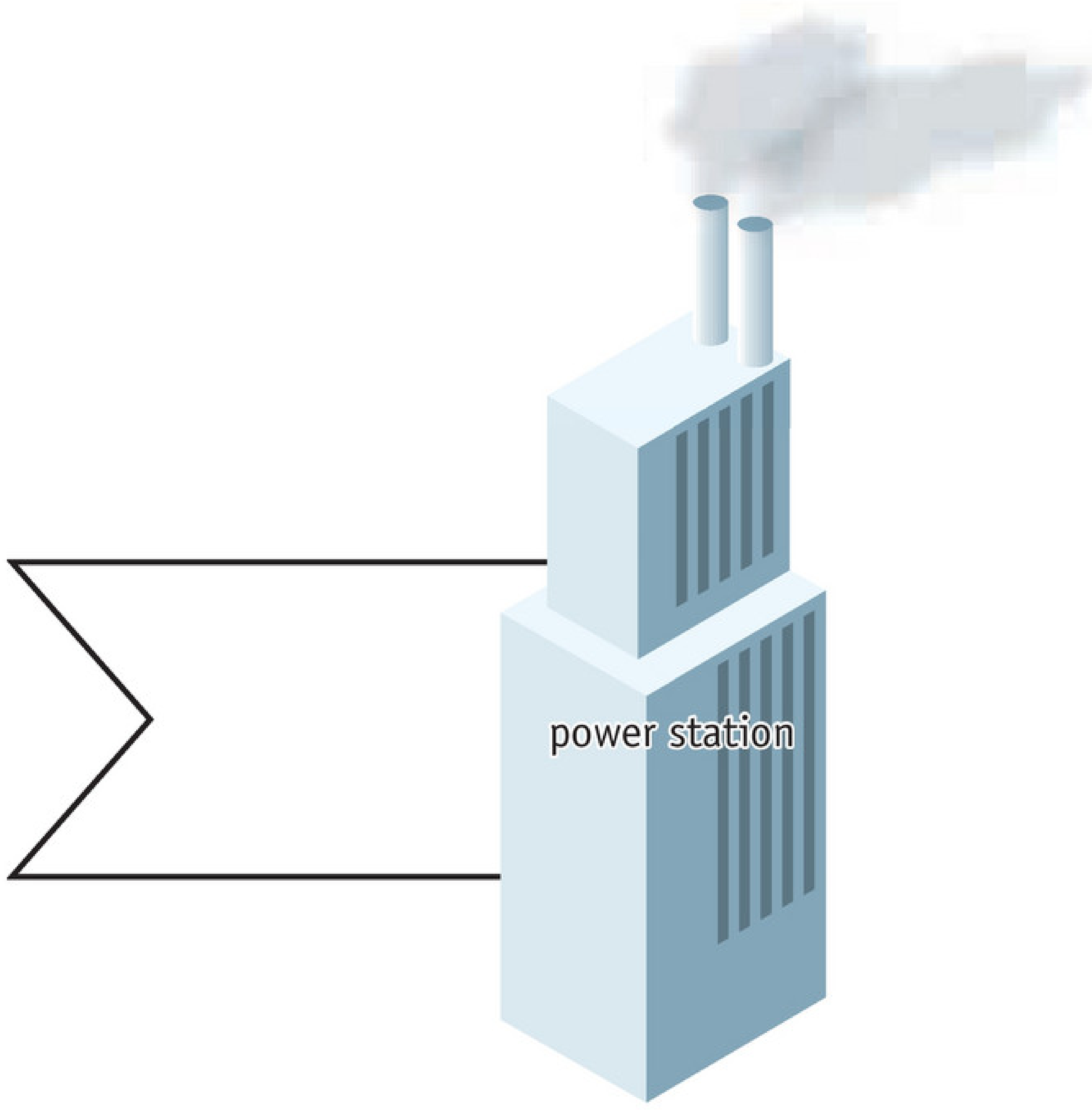


figure 7 The energy flow diagram for a gas-fired power station.

★ 4 For centuries, creative inventors have been trying to design a perpetuum mobile (Latin for ‘perpetual motion’). That is a device that always keeps going without having to put energy into it after it has been started up. Figure 8 gives an example of such a design.

a Explain why it is impossible for a perpetuum mobile to keep running forever.
b How is it possible for the atmosphere and the oceans to be in constant motion?

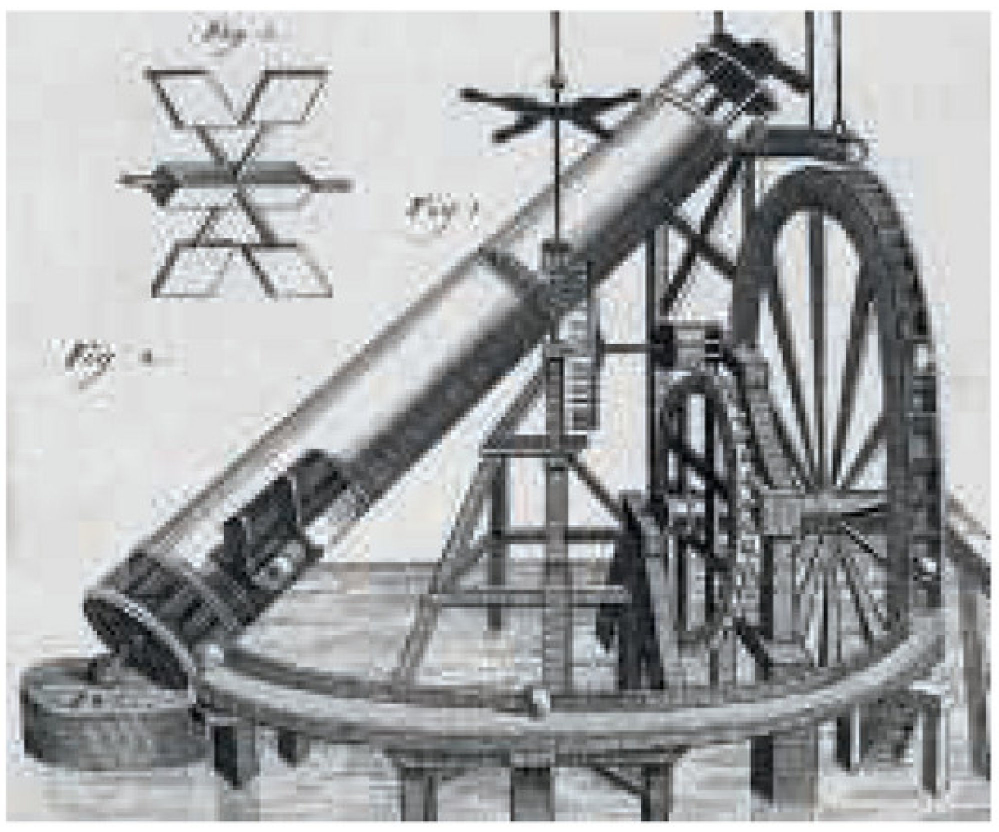


figure 8 A design for a perpetuum mobile by the German scientist Ulrich von Kranach from 1664.

5 Edward heats 100 mL water with a Bunsen burner. He measures the temperature every 30 s. Figure 9 shows a graph of his measurements.
After that, Edward heats 150 mL water. The flame of the Bunsen burner is just as large and hot as the first time.
Draw the graph for this experiment with 150 mL water in figure 9. Explain your graph.

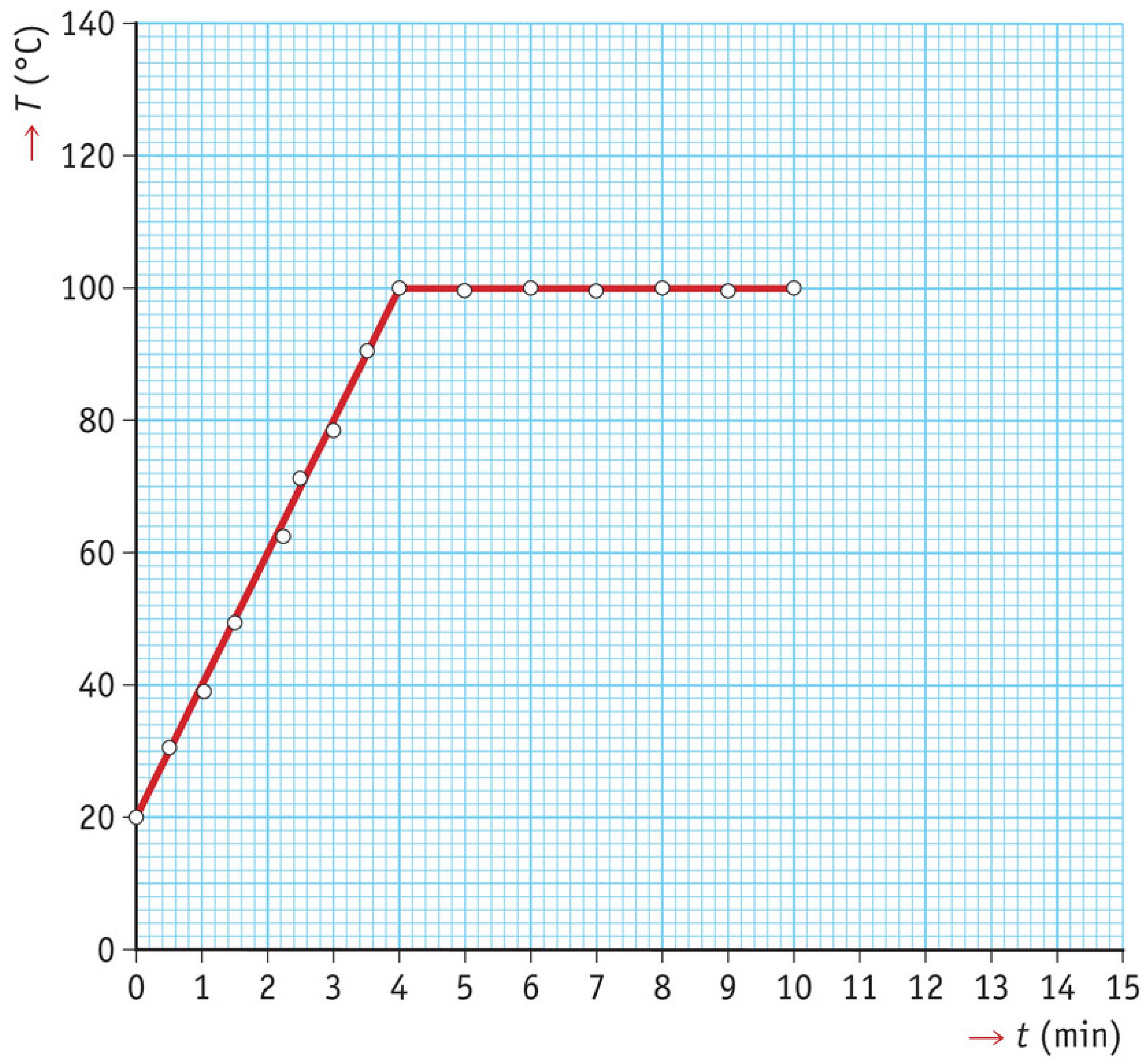


figure 9 Eddie's experiment.

6 Lisa heats 150 mL water in a calorimeter. Her measurements are given in figure 10.

a See the skills section on *Working with powers of ten*.
Calculate how much heat the water absorbs in 15 minutes.

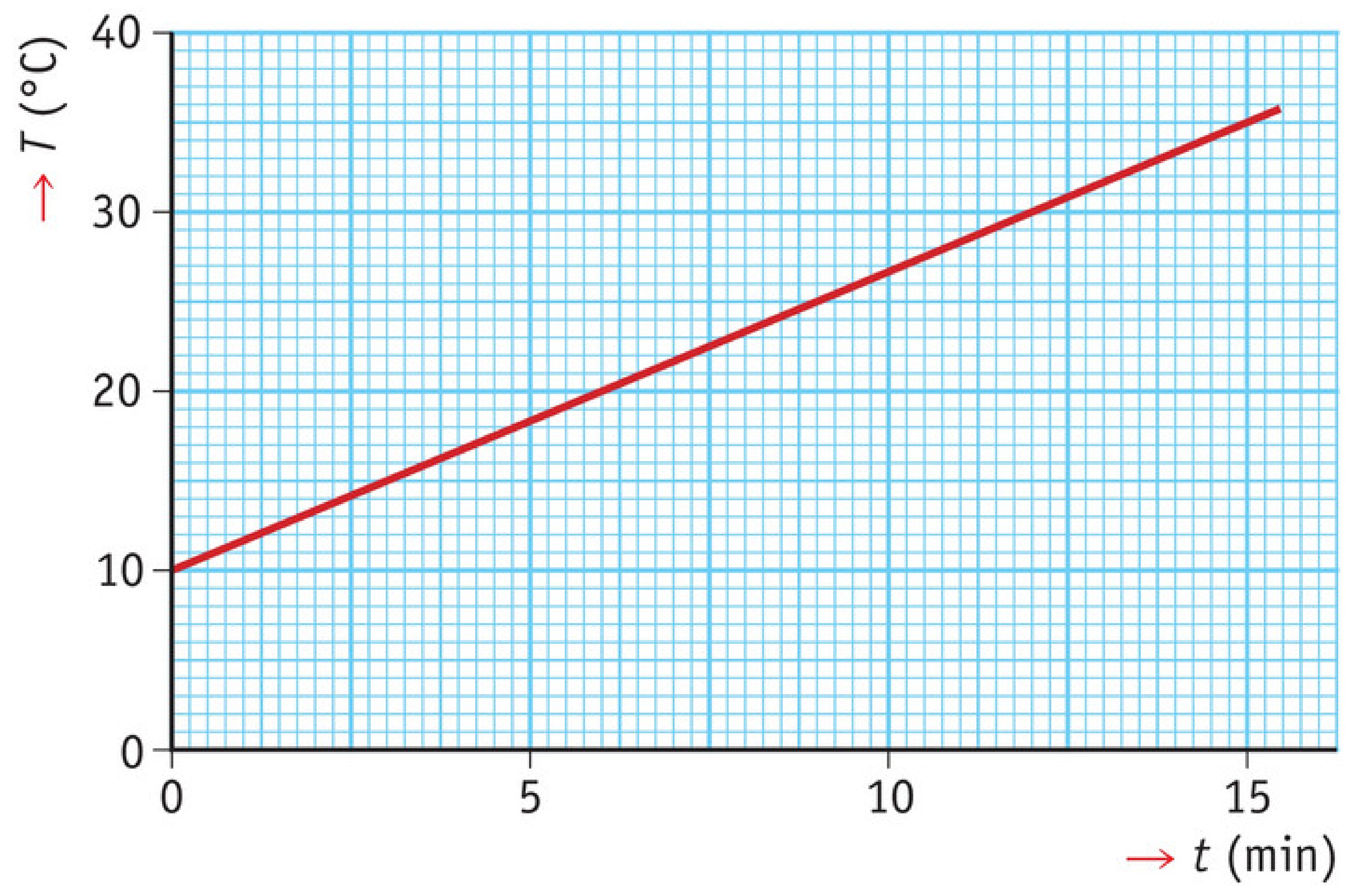


figure 10 Lisa's graph.

If you need more practice with *Calculations with specific heat*, go to the *Skills Trainer*.

b Calculate the power of the heating element.

c Your results for Exercise (b) will be a little bit too low compared to the actual rating. Why?

★ 7

John uses a plunger of 12 W to heat 100 g of liquid A first and then 100 g of liquid B. You can see the graphs of the two experiments in figure 11.

a Which liquid has the larger specific heat? How can you see that?

b Which of these two liquids could be water? Explain your answer.

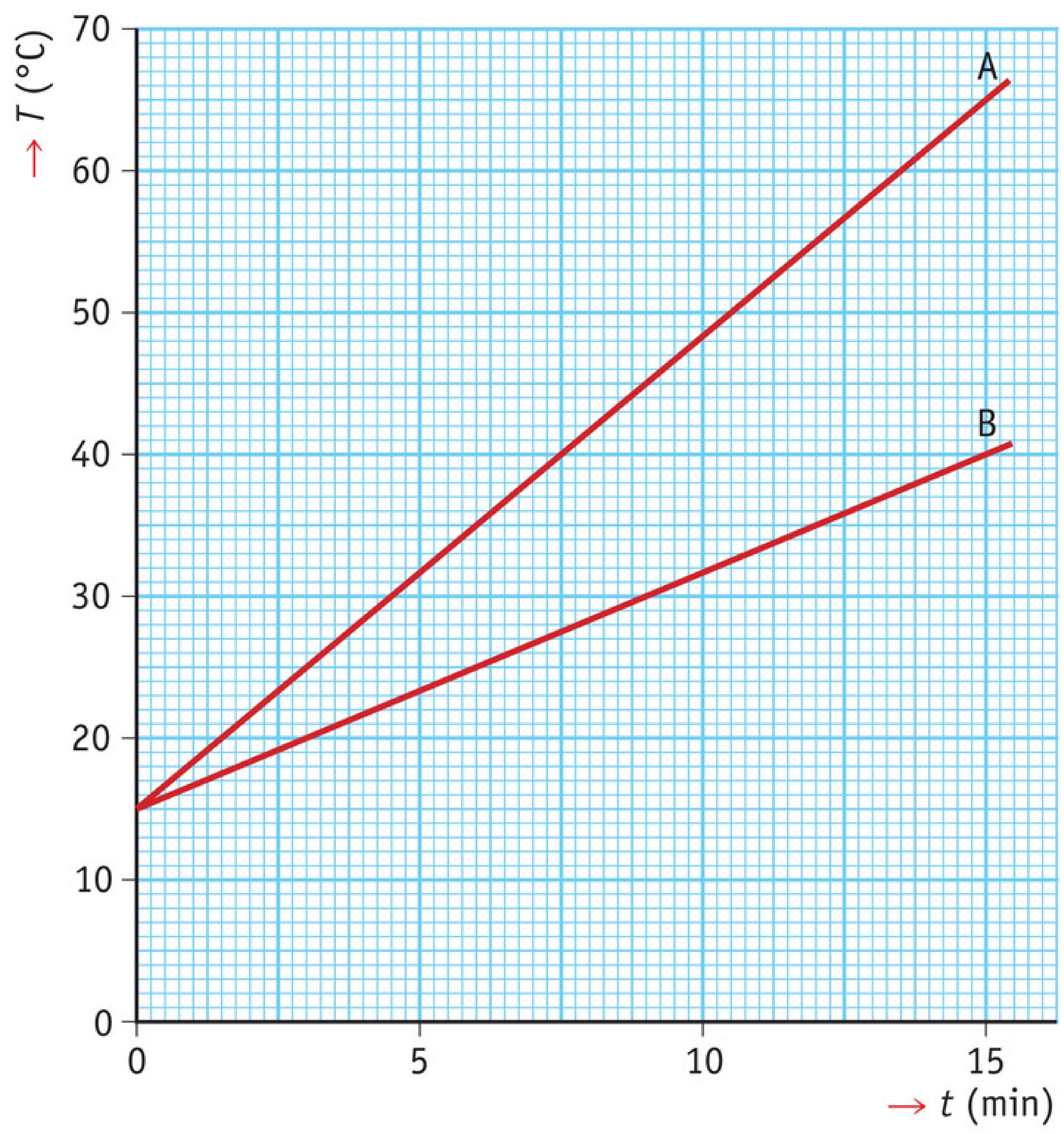


figure 11 John's graphs.

8

Joanne fills the electric kettle in figure 12 completely with water at 20 °C and turns the appliance on.

a Calculate how long it will take (at least) until the water boils.

b Explain why the exercise says 'at least'.

figure 12 Does it boil quickly or slowly?

Electric kettle

- volume 1.7 litres
- 2200 W
- removable jug
- boil-dry cut-out
- water level indicator
- attractive design
- two-year warranty

★ 9 Elsa makes 1.5 L tea at the campsite with a Bunsen burner (figure 13). She heats the water from 20 °C to 100 °C. Unfortunately, 50% of the heat produced flows past the pan and is lost. De fuel produces 46 kJ of heat per gram.
Calculate how many grams of fuel Elsa uses.

figure 13 Heating water.

Test what you know with *Test yourself*.

PLUS THE HEAT PUMP

10 Condensation of ammonia in a heat pump takes place at high pressure.

a Use the particle model to explain why condensation is easier that way.

b Underline the correct words and explain your answer.
When a gas condenses, *it absorbs heat*/*heat is released* and the temperature *increases*/*remains constant*/decreases.

11 In the house in figure 6, 12 L water from a stream flows past the pipes outside the house every second. The initial temperature of the water is 6.3 °C. The evaporating ammonia absorbs 21 kJ of heat from the water per second.

a Calculate the temperature of the water after it has flowed past the pipes. For the calculation, you may assume that 1.0 L water has a mass of 1.0 kg.

b The ammonia that has evaporated flows to the compressor. A few technical specifications about the operation of the compressor are given in table 1.

table 1 A few specifications for the operation of the compressor.

data	before the compressor	after the compressor
temperature of vapour	−17 °C	47 °C
pressure of vapour	0.19 MPa	1.9 MPa
voltage	380 V	
current	18.4 A	

Two rules apply for the ammonia vapour:

- The volume of the vapour is directly proportional to the temperature in kelvin (Rule 1).

Kelvin is a different unit for temperature that is often used in science.
The following applies:
T (in kelvin, K) = T (in °C) + 273

Convert the temperatures from the table into K.

c As well as Rule 1, there is a second rule for the vapour:
- The volume of the vapour is inversely proportional to the temperature (Rule 2).

See the skills section on *Measuring relationships*.

Enter the correct numbers and explain your answer with a calculation.
Just after the compressor, the temperature (in K) of the vapour has become

................× higher.

Just after the compressor, the pressure has become ....× as high.

d Calculate to what volume 1 dm^3 ammonia vapour was compressed just after the compressor. Use your answers to Exercise (c).

e The compressed ammonia vapour condenses and gives off a total of 21 kJ of heat to the house per second. You can calculate the electrical power consumed for this using the data from table 1.
Enter the correct number and explain your answer with a calculation.

For each kW of electrical power consumed, the pump supplies ....× as much heat per second to the house.

3 Insulating

LEARNING OBJECTIVES

3.3.1 You can explain ways that a house loses heat.

3.3.2 You can explain how a dynamic equilibrium is reached between heat loss and heat production.

3.3.3 You can calculate how much heat flows away through the wall of a house.

3.3.4 You can explain how you can reduce heat loss in a house.

PLUS 3.3.5 You can explain measures that the people living in a house can take to make the house energy-neutral.

When it is cold outdoors, a lot of heat from poorly insulated houses disappears outside. You can reduce the heat loss by insulating walls, windows, floors and roofs better. This not only makes the house more comfortable but also helps keep energy bills low.

HEAT LOSS

If the temperature indoors is higher than the temperature outdoors, the house is continuously losing heat to the surroundings. This happens fastest when the wind is blowing because the wind carries away the warmer air that is in and close to the house. Even if there is no wind, heat still continuously leaks away. This happens in three ways: by **conduction**, by **convection** and by **radiation** (figure 1).

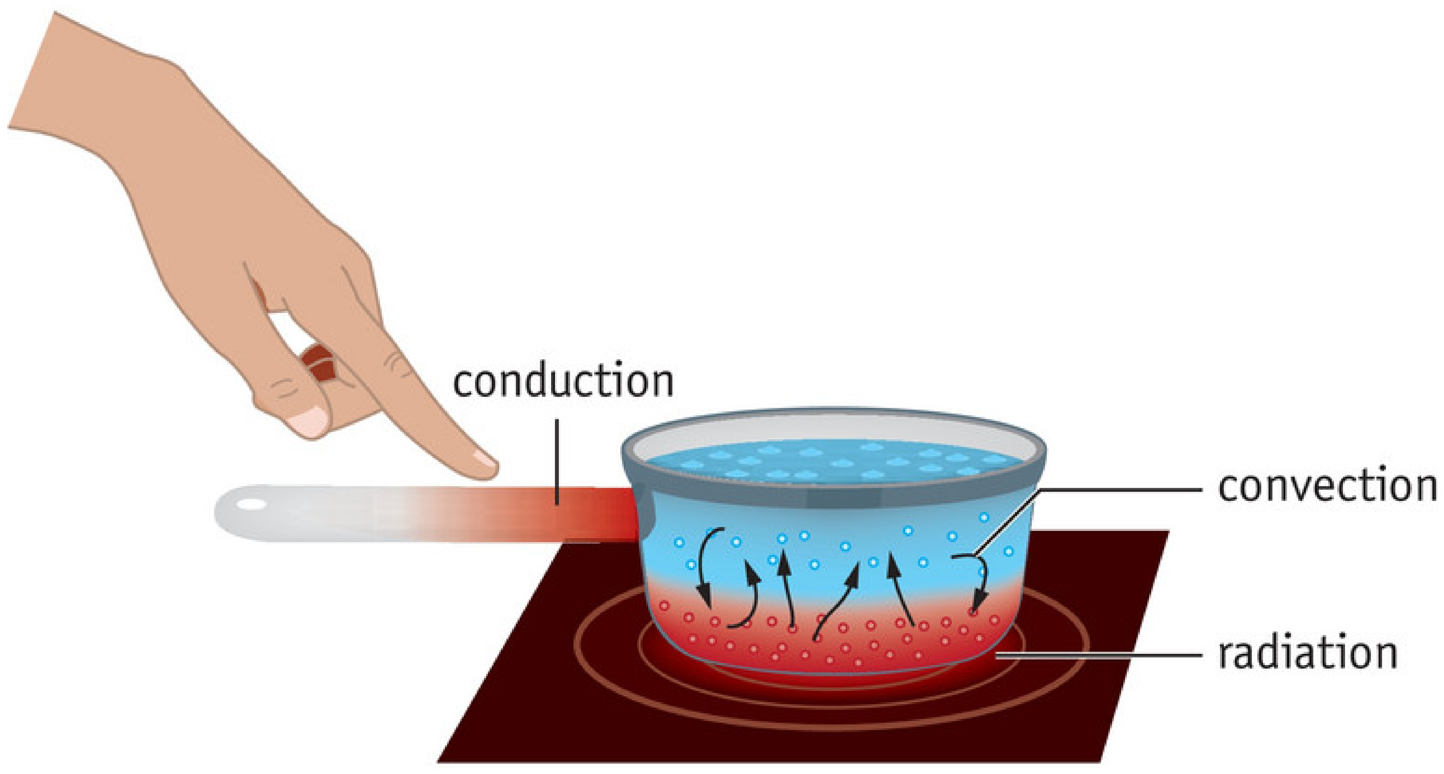


figure 1 Conduction, convection and radiation in the kitchen.

Conduction

In conduction, the heat spreads through a substance, such as brick or glass. This is because the molecules are continually colliding with one another, passing their kinetic energy from one to the next. This is how heat spreads from the place where the temperature is higher to where the temperature is lower. Metals conduct heat well; wood and plastic are poor thermal conductors.

Convection

When you heat a liquid or gas, convection can occur. You can see that for instance in the air at home. The air next to the radiators warms up: it expands and so gets a smaller density, which makes the heated air rise and take the heat with it. Further up, the air cools down and falls again.

Radiation

Everything around you – including your own body – emits radiation: tiny packets of radiant energy are passed to the surroundings. The greater the temperature difference between an object and its surroundings, the more radiant energy the object emits. That is why a warm house loses more heat in the winter than in the summer (figure 2).

figure 2 A thermogram makes it possible to see the infrared radiation being emitted by a house.

Conduction, convection and radiation are very different processes. All three have the same effect: heat spreads from the place with the higher temperature to places with lower temperatures. Objects with higher temperatures than their surroundings are continuously losing heat.

DYNAMIC EQUILIBRIUM

The temperature indoors only remains constant when the heating is supplying just as much heat as the house is losing (figure 3). Heat production and heat loss are then in balance. When you set the heating to a higher setting, the heat production becomes greater than the heat loss. The temperature indoors then starts to rise.

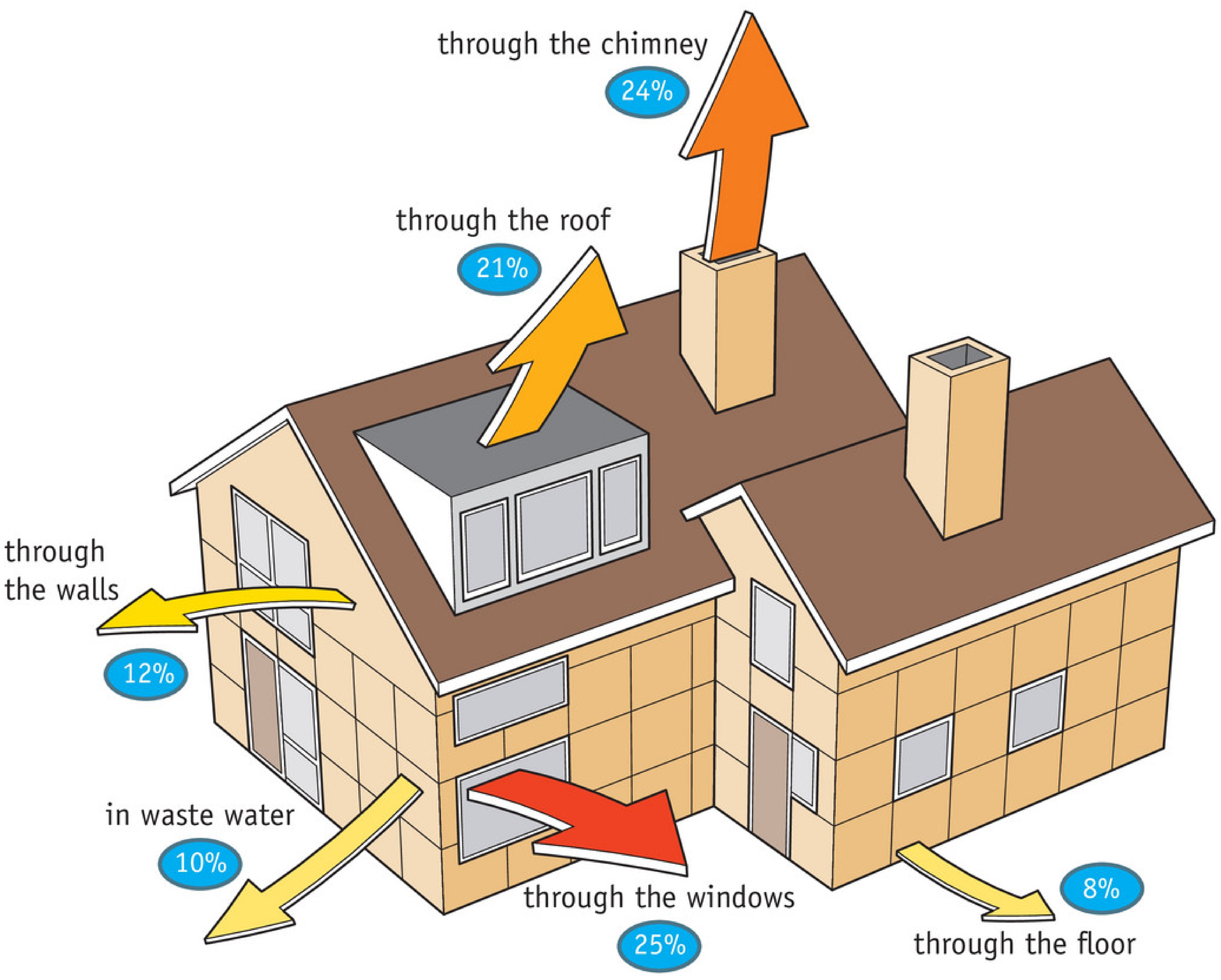


figure 3 Heat loss from a poorly insulated house.

In such a situation, the temperature will not keep increasing, though. This is because the heat loss also increases as the temperature rises. At some specific point at the higher temperature, the heat production and heat loss will be in balance again. You say that there is a **dynamic equilibrium** between heat production and heat loss: the balance is re-established with every change.

Good **insulation** can reduce the heat loss of a house. Less heat is needed to keep the temperature indoors constant. Even in a well-insulated house, a balance between heat production and heat loss arises naturally when you turn the heating on. However, the amount of heat required to achieve the equilibrium is much smaller.

WALL INSULATION

The walls of houses are often made of brick. This building material conducts heat relatively well, which means that a lot of the heat from a house can disappear outside through the walls. How much heat flows outside through a wall per second depends on:

- the temperature difference ΔT between outdoors and indoors;
- the surface area A of the wall;
- the quality of the insulation. The quality is indicated by the U value in $W/(m^2 \cdot °C)$. The higher the U value, the greater the heat loss through the wall. A well-insulated wall has a low U value; a poorly insulated wall has a high U value.

You can calculate the amount of heat Q_w that flows away through a wall per second using the formula:

$$Q_w = U \cdot A \cdot \Delta T$$

where:

- Q_w is the heat loss per second, in joules per second (J/s);
- U is the U value of the wall, in $W/(m^2 \cdot °C)$;
- A is the surface area of the wall in square metres (m^2);
- ΔT is the temperature difference between outdoors and indoors, in degrees Celsius (°C).

You can significantly reduce the U value by insulating a wall, for instance using glass wool, rock wool or polystyrene (figure 4). These insulation materials are full of air in small cavities. Air conducts heat very poorly, so the U value decreases considerably. A layer of insulation material 5 cm thick can make the heat loss through a wall 4× smaller.

figure 4 Insulation materials consist largely of air.

INSULATING A HOUSE

There are also other ways of insulating a house. You can, for example:

- replace single and double glazing with much better insulating HR++ or HR+++ glass (figure 5);
- fill the cavity (the space between the internal wall and the external wall) with insulation material;
- install an insulating layer of glass wool or rock wool, polystyrene or bubble wrap film in roofs and under floors;
- insulate heating pipes and hot water pipes in places where they run through cold spaces, such as a garage or a cellar;
- seal cracks with a weatherstrip (draught excluder).

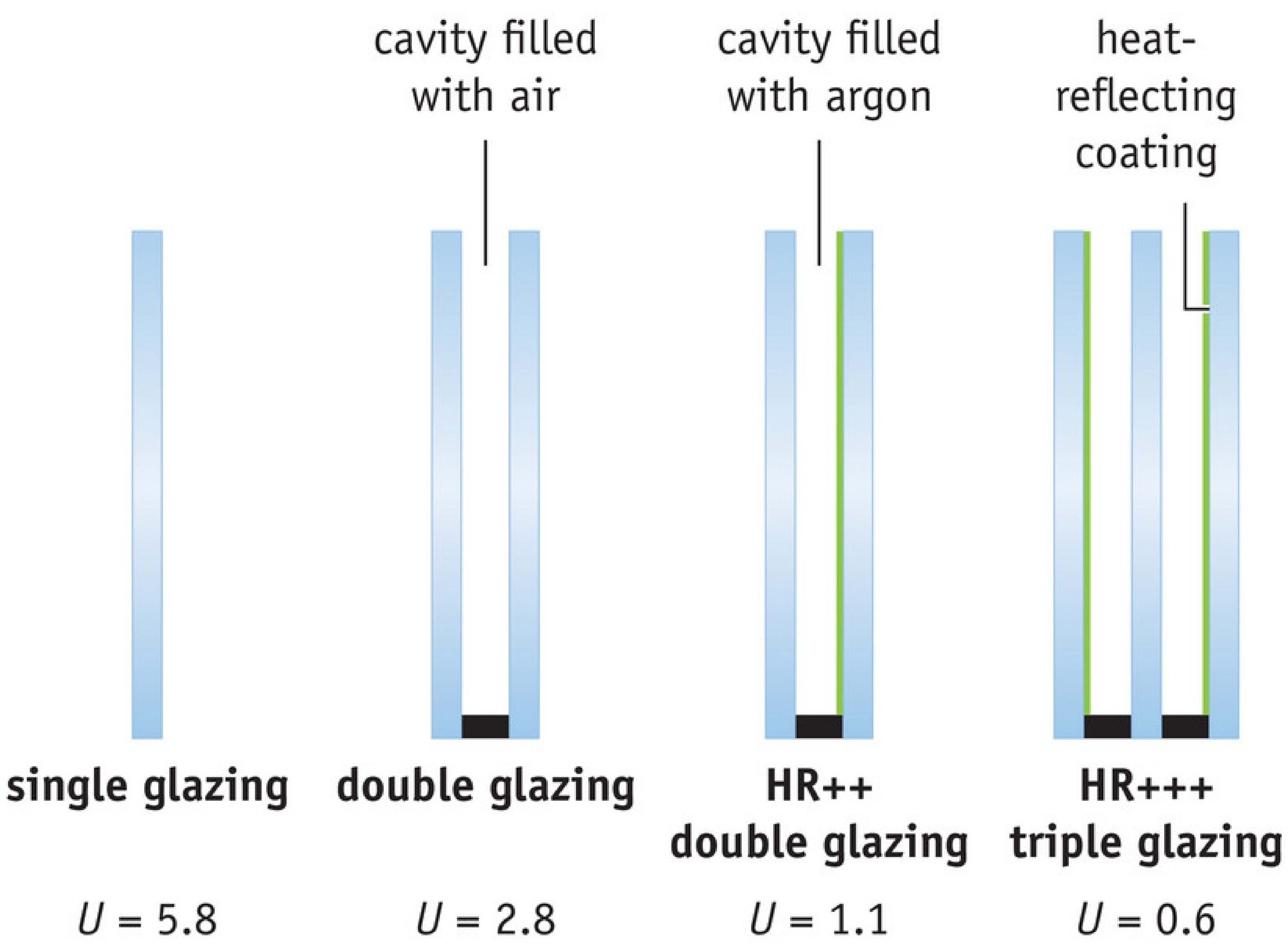


figure 5 Single glazing, double glazing, HR++ glass and HR+++ glass.

EXAMPLE EXERCISE 1

Anna reads in a flyer that you can save a lot of energy by insulating central heating pipes: about 10 m^3 of natural gas per metre of piping per year.
1 m^3 of natural gas provides $32 \cdot 10^6$ J of heat.
Anna insulates 15 m of central heating pipes in her house.
How much heat does she save every year?

given	insulating 1 m of pipes saves 10 m^3 of natural gas per year. 1 m^3 natural gas provides $32 \cdot 10^6$ J of heat.
required	heat saving per year
working	insulating 15 metres of pipes saves $15 \times 10 = 150$ m^3 natural gas per year. That is equivalent to $150 \times 32 \cdot 10^6 = 4.8 \cdot 10^9$ J = 4.8 GJ of heat.

PLUS ENERGY-NEUTRAL LIVING

Quite a lot of chemical and electrical energy is used in an average home. The residents will notice that when they take the meter readings for the annual energy bill. The electricity consumption of an average Dutch household in 2019 was 3000 kWh and the average gas consumption was 1500 m^3. That makes for a total energy bill of over € 1,840 (including standing charges, 2019 prices).

The residents can reduce their energy bill by insulating their house properly. This lets them prevent energy from being used unnecessarily for heating. More and more people are choosing to generate part of their energy requirement themselves. Ways to do this include placing solar panels or solar collectors on the roof. All these measures result in a lower energy bill.

The government would like buildings to be **energy-neutral** in the future. That means that a building generates as much energy as it uses, taken over the year as a whole (figure 6).

figure 6 An energy-neutral house. Insulation keeps the heat loss as low as possible. The house generates the necessary energy itself.

Practice the concepts using the *Flash cards*.

COURSE MATERIAL

1 Answer the following questions.

- **a** In what direction does the heat spread in conduction, convection and radiation?
- **b** Why are you not able to reuse the heat that a house loses?
- **c** Why does a heat source have to deliver heat to a house continuously if the weather is cold?
- **d** Why does insulation material such as polystyrene consist mainly of air?
- **e** What does “there is a dynamic equilibrium between heat production and heat loss” mean?

2 Indoor heat disappears outside through a wall.

- **a** What formula can you use to calculate the heat loss?
- **b** What three factors affect the heat loss according to this formula?
- **c** Which of these factors changes if you insulate a wall? And how?

IN PRACTICE

3 Figure 7 shows a bucket standing under an open tap. The bucket has a hole in the bottom.

a Explain why the water level in the bucket no longer changes after a while.

b If you open the tap even more, the water level will rise at first.
Why does the water level soon stop rising?

c You can compare the bucket in figure 7 to a house that is being heated.
Complete the table below.

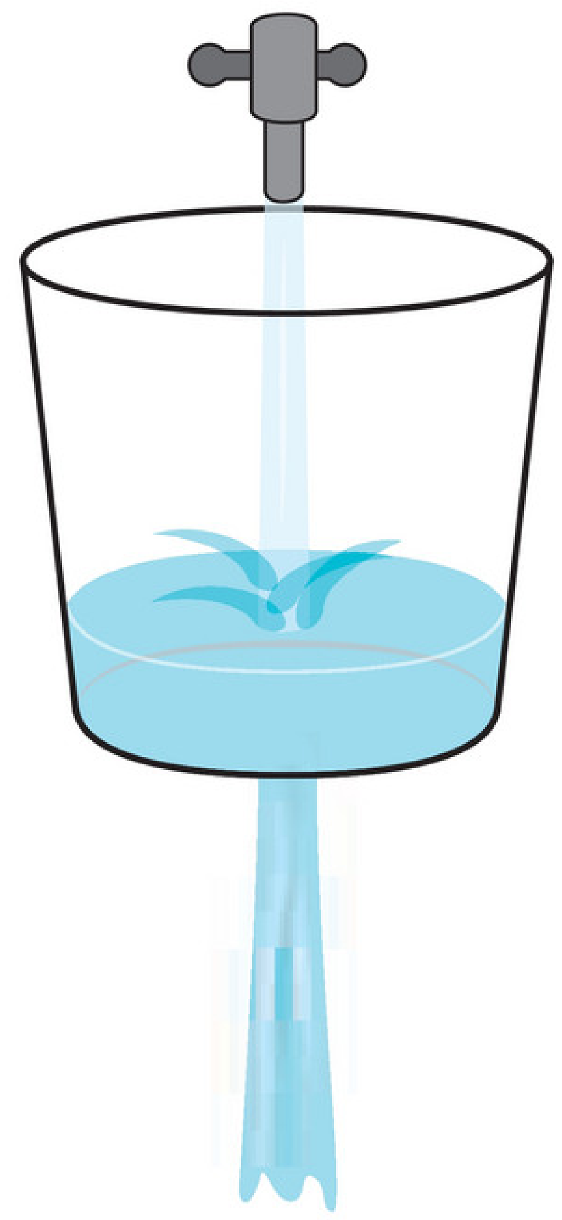


figure 7 A bucket in dynamic equilibrium.

This part of figure 7	is like:
the bucket	a house that is being heated
the tap above the bucket	
the water from the tap	
the water level in the bucket	
the water flowing out	

4 When it freezes outside and you get your bicycle from the shed, the handlebars feel much colder than the saddle.
Give an explanation for this.

5 Fans of natural ice hate snow. If the ice has a thick layer of snow on it, the ice layer will hardly grow any thicker, even though it's freezing cold.
Explain why the ice does not get any thicker despite the temperature staying well below zero.

6 When new houses are being built, a lot of attention is paid to reducing their energy consumption. Such a house often has large windows on one side so that heat can get in even in the middle of the winter.

a What energy source is helping heat the house then?

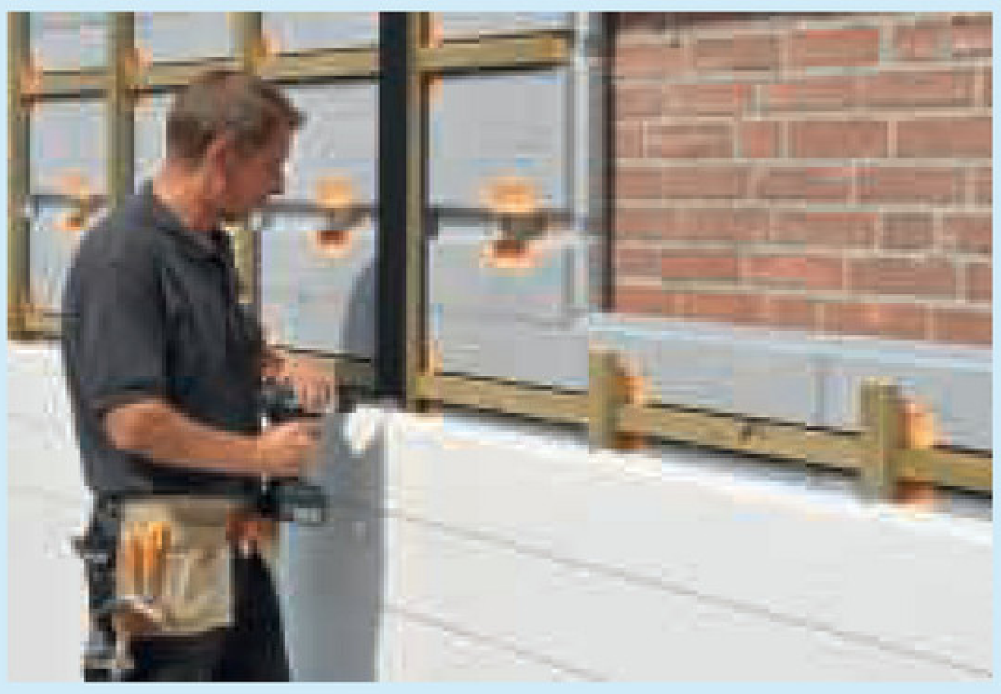
b What form of heat transport gets that heat inside the house?

c Which side of the house is it best to put a window on for this: the north, south, east or west?

d Which side of the house is it better to have only small windows on?

7 Sebastian has bought an old house with insulated cavity walls. He thinks his energy consumption is still too high, though. He reads in a brochure that he can save a lot of energy and money with stud walls (figure 8).

Stud walls on the external wall: a great idea!



A well-insulated cavity wall allows far less heat through than an empty cavity wall. The heat loss through that type of insulated wall is 256 MJ (8 m^3 natural gas) per square metre per year. Adding an extra stud wall up against the external wall results in even lower energy losses; only 80 MJ per square metre per year. Placing a stud wall outside your cavity walls is therefore very much to be recommended. It can save you hundreds of euros a year.

figure 8 Part of a brochure about cavity wall insulation.

a According to the brochure, how much heat disappears per year through 1 m^2 of an insulated cavity wall without an extra stud wall?
b According to the brochure, how much heat disappears per year through 1 m^2 of an insulated cavity wall with a stud wall?
c Sebastian decides to put in stud walls. In total, he gets a wall area of 55 m^2 insulated this way.
Calculate how much less heat now disappears from his house per year.
d Sebastian's house is heated with natural gas.
Calculate how many m^3 of natural gas Sebastian will save annually.
e Calculate how much lower Sebastian's annual energy bill is.
1 m^3 natural gas costs € 0.75.
f The brochure states that cavity wall insulation 'can save you hundreds of euros per year'.
Do you agree with this statement? Explain your answer.

8 Susan has bought an old house with single-glazed windows. She reads on a website that a lot of heat is lost through single glazing (figure 9).
a The windows of Susan's house have a total surface area of 14 m^2.
Calculate how many m^3 natural gas disappears in the form of heat through the windows per cold season.
b Susan decides to replace all of the single glazing with HR++ glass.
Calculate how many m^3 of natural gas she will save per cold season.
c HR++ glass costs € 120 per m^2 (including installation). Natural gas costs € 0.75 per m^3.
Calculate how long it will take before Susan has earned back the costs of the double glazing, assuming that the price of gas does not change.

U value

You use the *U* value to estimate the heat loss through a roof, window or floor. The following rule of thumb can be used for this:
The heat loss per year through 1 m^2 of a roof, wall or window corresponds to consuming $10 \times U$ m^3 natural gas.
A few examples (with *U* in W/(m^2·°C))
- single-glazed window: $U = 6$
- double-glazed window: $U = 3$
- HR++ glass window: $U = 1.1$
- unfilled cavity wall: $U = 1.8$
- filled cavity wall: $U = 0.8$

figure 9 A website about the *U* values of windows and walls.

★ 9 Exercise 8 (continued).

The temperature on a winter's day is −4 °C. It is nice and warm inside at a temperature of 20°C.

- **a** Use $Q_w = U \cdot A \cdot \Delta T$ to calculate how many joules of heat Susan saves per second by installing HR++ glass.
- **b** Calculate the savings in MJ per day if the heating is on during the day (16 hours).
- **c** The calorific value of natural gas is 32 MJ/m³.
  Calculate how many m³ natural gas Susan saves per day.
- **d** On most days of the year, Susan will save a lot less natural gas.
  Explain why.

Test what you know with *Test yourself*.

PLUS ENERGY-NEUTRAL LIVING

10 The roof of the house in figure 6 sticks out quite a long way at the front.

- **a** Explain why only the south side of the house has a part that sticks out like that.
- **b** Why is it that not a lot of sunlight gets into the house during the summer?
- **c** Why is it that the people living there do get 'a lot of sun inside' during the winter?
- **d** Explain what benefits this kind of construction has for the energy bills.

11 Search on the Internet for information about energy-neutral houses.

- **a** What measures are taken to reduce the energy consumption in the house?
- **b** What measures produce a net positive balance of energy that you can use in the house?
- **c** Does an energy-neutral house use energy that was not generated by the house itself? How does that get compensated so that the house can still be called 'energy-neutral'?

12 The house in figure 6 is energy-neutral because its features include the use of solar panels. A solar panel is 1.00 m wide and 1.70 m high and has a peak power of 330 W. The sun does not always shine, so the average power is much lower than the peak power. On average, a solar panel generates 280 kWh of electrical energy per year.

- **a** Calculate the average power of a solar panel.
- **b** Without extra insulation or energy-saving measures, a house cannot be energy-neutral.
  Use figure 6 and a calculation to show that this statement is true. Assume an average Dutch household, which needs 3000 kWh of electrical energy plus the energy from 1500 m³ gas. 1 m³ gas supplies 8.9 kWh.

4 Efficiency

LEARNING OBJECTIVES

3.4.1 You can use an energy flow diagram to explain how efficiently a device uses energy.
3.4.2 You can calculate the efficiency of a device in terms of energy.
3.4.3 You can calculate the efficiency of a device in terms of power.
PLUS 3.4.4 You can explain how industrial residual heat can be usefully used.

There are various benefits to being economical with electrical and chemical energy. You can save money by doing it, reserves of natural gas and coal are used up less quickly, and you can help reduce environmental problems.

SAVING ENERGY

You can see from the formula $E = P \cdot t$ that there are two ways of saving energy. You can make the power P smaller by buying energy-efficient appliances such as a refrigerator with an A+++ energy label or an energy-efficient tumble dryer. Or you can make the time t smaller by using the appliances you already have less often or for less long, for instance by taking shorter showers or by drying the laundry on a washing line in good weather.

One appliance having a lower power rating than another does not necessarily mean a great deal. There is only any point to the comparison of the two devices are doing something similar. You can compare the power consumption of two bulbs that give the same amount of light, for example an energy-saving bulb and a LED light. You can see that LED light has a much lower power rating than a comparable energy-saving bulb.

Figure 1 shows you the energy flow diagrams of an energy-saving bulb and a LED light. An energy-saving bulb converts 25% of the electrical energy into light; the rest is converted into heat. We can say that an energy-saving bulb has an **efficiency** of 25%. LED lights do better: they convert 50% of the electrical energy into light. The efficiency of that type of bulb is therefore 50%.

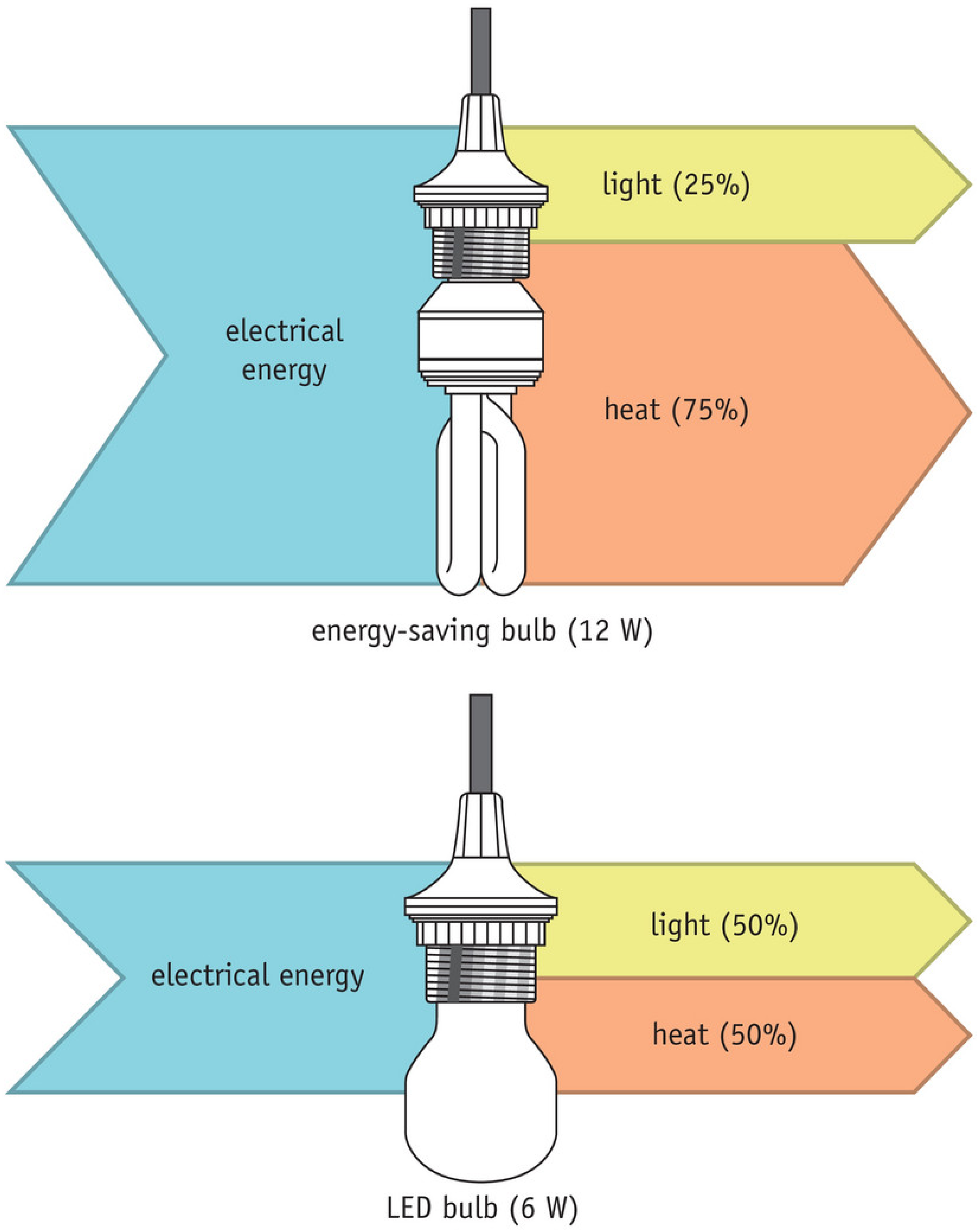


figure 1 Two energy flow diagrams.

CALCULATING THE EFFICIENCY

EXP. 2+3

You can calculate the efficiency η (a Greek letter called eta) of a device with the formula:

$$\eta = \frac{E_{useful}}{E_{tot}} \cdot 100\%$$

where:

- η is the efficiency in percent (%);
- E_{useful} is the amount of energy that is usefully used in joules (J);
- E_{tot} is the overall amount of energy that is converted, in joules (J).

E_{useful} is the useful energy that you started with. In a lamp, that is the amount of light (a form of radiant energy) that the bulb produces. E_{tot} is the amount of energy that the device consumes in total. In a lamp, that is the amount of electrical energy used.

You also get the right answer if you fill in:

- the amount of energy per second that is used usefully;
- the overall amount of energy that is converted per second.

Energy per second is the same as power. In other words: you can also calculate the efficiency by dividing the actual power by the total power.

$$\eta = \frac{P_{useful}}{P_{tot}} \cdot 100\%$$

where:

- η is the efficiency in percent (%);
- P_{useful} is the useful power produced by the appliance in watts (W);
- P_{tot} is the overall rating of the appliance in watts (W).

EXAMPLE EXERCISE 1

When the sun is shining brightly, the incoming irradiation at an alpine hut is 1000 W/m^2.
A solar panel with a surface area of 1.8 m^2 supplies a maximum power of 288 W (figure 2).
Calculate the efficiency of this solar panel.

given $P_{tot} = 1.8 \times 1000 = 1800$ W
$P_{useful} = 288$ W

required $\eta = ?$

working $\eta = \frac{P_{useful}}{P_{tot}} \cdot 100\% = \frac{288}{1800} \times 100\% = 16\%$

figure 2 The roof of this alpine hut has space for three solar panels of 1.8 m^2 each.

A HIGH-EFFICIENCY COMBINATION BOILER

The boiler of a heating system burns natural gas (figure 3). The hot combustion gases that this produces go past pipes that water is flowing through: the heat exchanger. Part of the heat is then transferred to the water. The remaining heat disappears outside along with the combustion gases. Changing the position of the diverter valve allows water for the hot water taps and shower to be heated in the hot water cylinder.

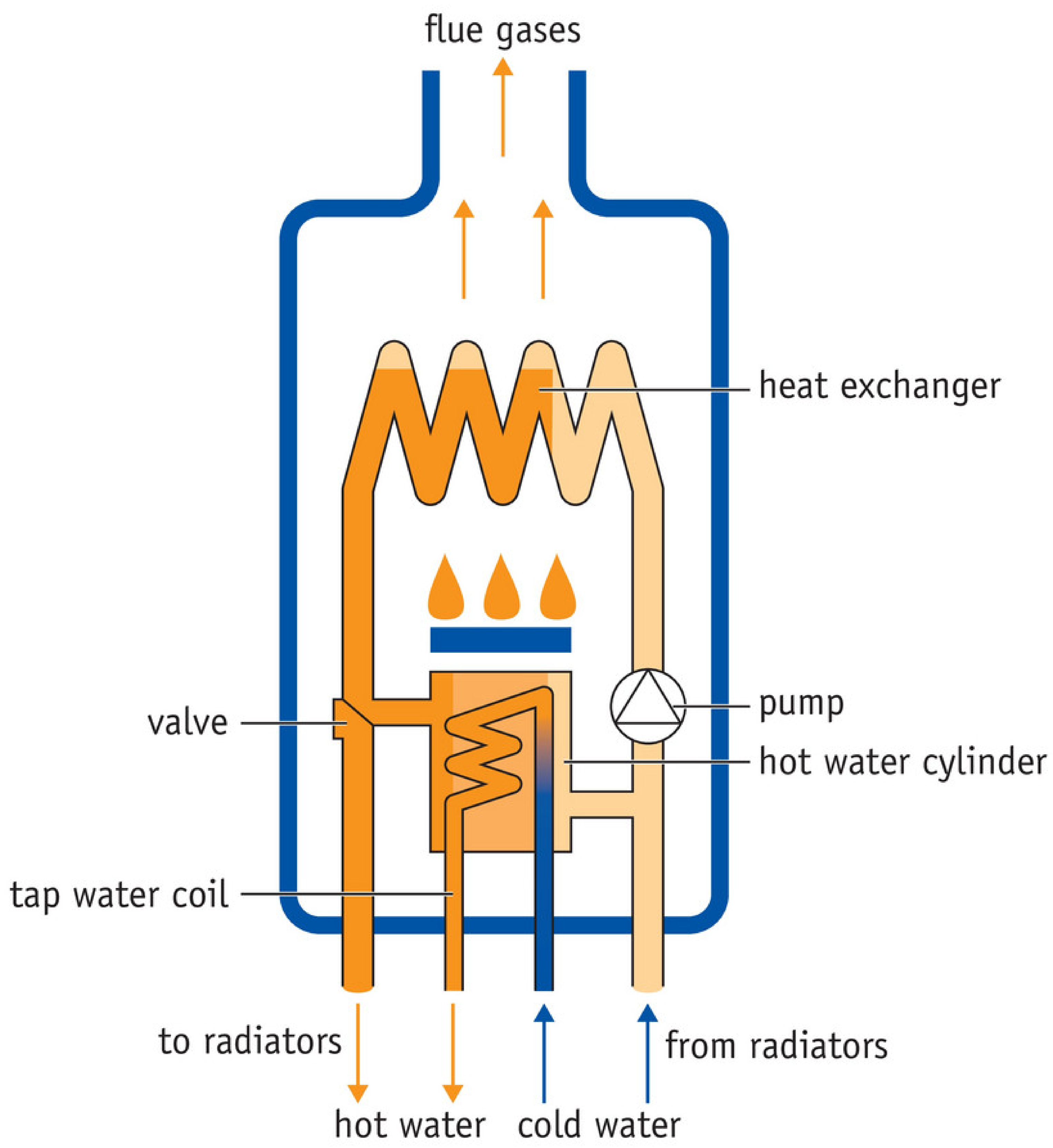


figure 3 A schematic overview of a high-efficiency combination boiler.

To determine E_{tot} (the total amount of energy converted) by a boiler, you need to know how much heat the gas that was burned had produced. To calculate that, you need two pieces of information: the volume of natural gas burned (in m^3) and its **calorific value** as a fuel. The calorific value of Dutch natural gas is 32 MJ/m^3. That means that 32 MJ of heat is released if you burn 1 m^3 of natural gas.

To determine E_{used} (the amount of usefully used energy), you have to determine how much of that heat ended up in the water. To find that out, you measure the mass m and the temperature increase ΔT for the water that has been heated up. You can then calculate the amount of heat that the water has taken up using the formula $Q = c \cdot m \cdot \Delta T$.

If you know E_{tot} and E_{used}, you can finally calculate the efficiency of the central heating boiler. Tests have shown that central heating boilers fifty years ago were about 65% efficient. The efficiency of a modern HE (high efficiency) combination boiler is over 90%.

EXAMPLE EXERCISE 2

A combi-boiler burns 0.12 m^3 natural gas and heats 11 litres of water from 18°C to 72°C (figure 4).
Calculate the efficiency of the combi-boiler.

1 Calculate E_{tot} = the amount of heat the natural gas has provided.

given	0.12 m^3 natural gas has been burned. The calorific value of natural gas is 32 MJ/m^3.
required	E_{tot} = ?
working	$E_{tot} = 0.12 \times 32 = 3.84$ MJ

2 Calculate E_{used} = the amount of heat that ended up in the water.

given	The mass m of 11 L water = $1.1 \cdot 10^4$ g. The temperature increase $\Delta T = 72 - 18 = 54$°C. The specific heat c of water = 4.2 J/(g·°C).
required	E_{used} = ?
working	$E_{useful} = Q = c \cdot m \cdot \Delta T = 4.2 \times 1.1 \cdot 10^4 \times 54$ $= 2.49 \cdot 10^6$ J = 2.49 MJ

3 Calculate the efficiency of the combined boiler.

given	E_{tot} = 3.84 MJ E_{nut} = 2.49 MJ
required	η = ?
working	$\eta = \dfrac{E_{useful}}{E_{tot}} \cdot 100\% = \dfrac{2.49}{3.84} \times 100\% = 65\%$

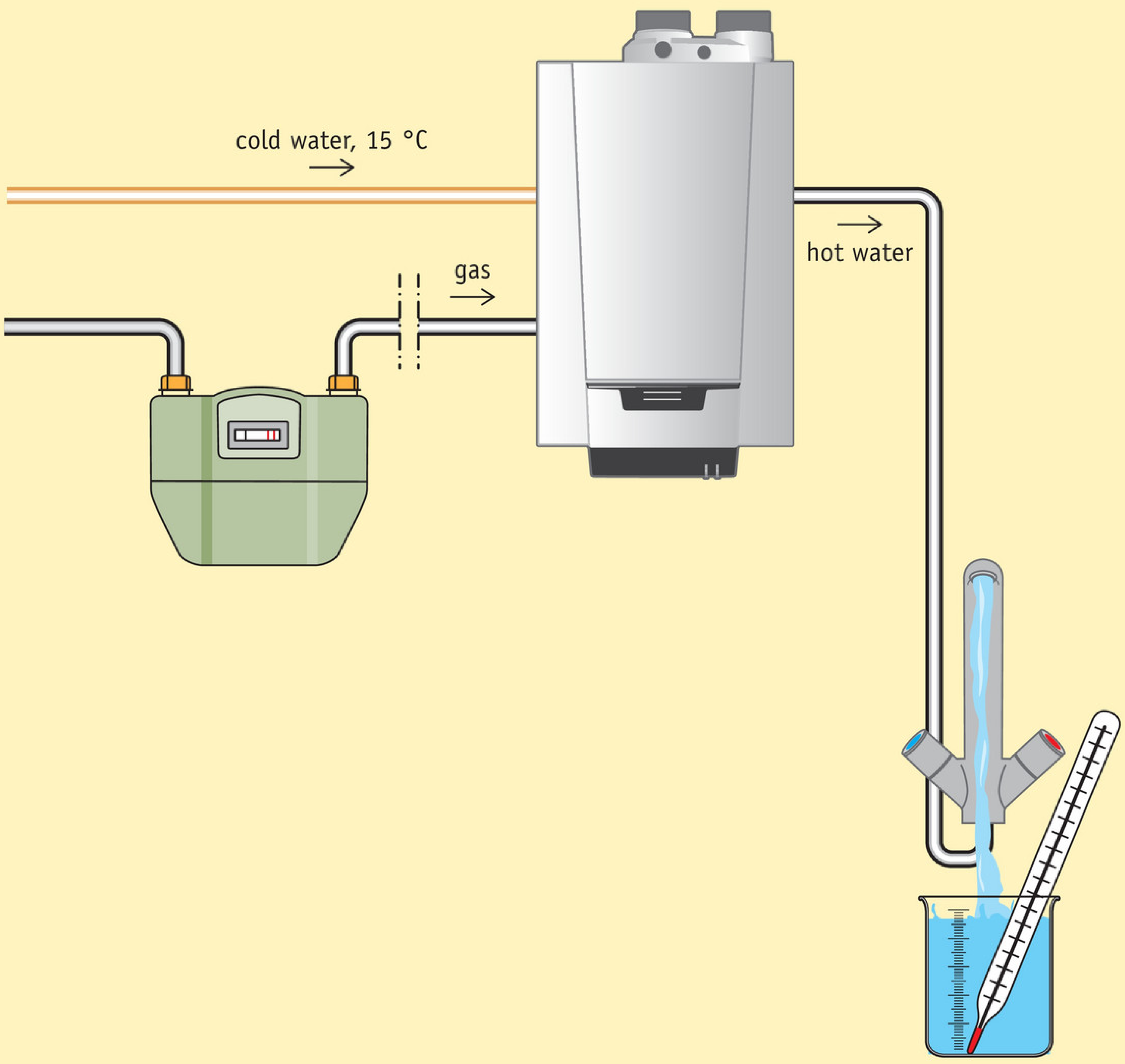


figure 4 This is how you can determine the efficiency of a central heating boiler.

PLUS USING RESIDUAL HEAT USEFULLY

Power stations have an efficiency of only about 40%. The other 60% is residual heat that is carried away via a cooling system. In a power station that provides **combined heat and power**, a large part of the residual heat is also used usefully, for example to heat homes or greenhouses near the power station. This increases the efficiency of the power station to over 80%. In 2020, approximately 410,000 households in the Netherlands are using this type of district heating (figure 5).

figure 5 Construction of district heating.

Combined heat and power is also used often in factories, which need a lot of both heat and power. Power in this case means both generating electric current and powering machinery. The heat, also called **industrial residual heat**, can often be used usefully somewhere nearby. For instance, in Aalsmeer the residual heat from a data centre is used to heat a swimming pool, a childcare facility and a business that exports potted plants.

Practice the concepts using the *Flash cards*.

COURSE MATERIAL

1 Answer the following questions.

a How can you see from the formula $E = P \cdot t$ that there are two ways of making savings on your energy bill?
b Describe in your own words what the “efficiency of a device” means.
c What formulas can you use to calculate the efficiency of an appliance?
d What does the “calorific value of a fuel” mean?

2 You need to make various measurements with measuring instruments in order to determine the efficiency of an HE combi-boiler.

a You can use a .... to determine how many cubic metres of natural gas have been burned.

b You can use a .... to determine much hot water the HE combi-boiler has produced.

c You can use a .... to determine how much that water’s temperature increased.

IN PRACTICE

3 Figure 6 shows you three energy flow diagrams.
Calculate the efficiency of each of the energy conversions.

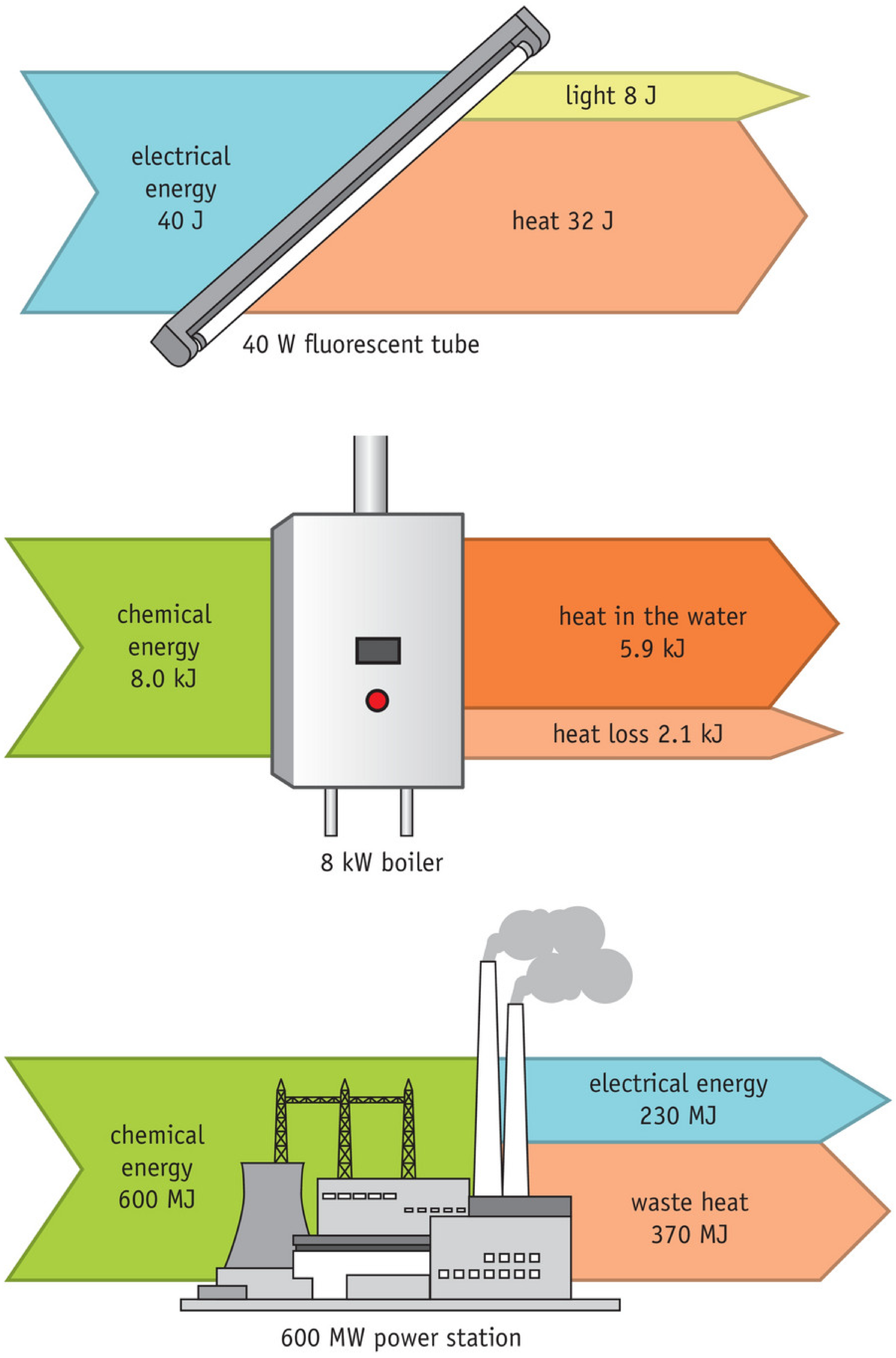


figure 6 Three energy flow diagrams.

4 Burning 1 m^3 natural gas generates 32 MJ of heat.

a Calculate how many megajoules of that is used usefully in an old-fashioned central heating boiler (η = 75%).

b Calculate how many megajoules of that is used usefully in a modern HE boiler (η = 93%).

★ 5 Mahmood's desk light has a halogen bulb. The bulb is connected to the socket via a mains adapter. The mains adapter consumes 24 W of electrical power (at a voltage of 230 V) and gives out 19 W of electrical power (at a voltage of 12 V).

a Calculate the efficiency of the adapter.

b What happens to the 5 W of power that is not usefully used? How can you see that?

c Complete the energy flow diagram in figure 7. Make sure each arrow is the right height.

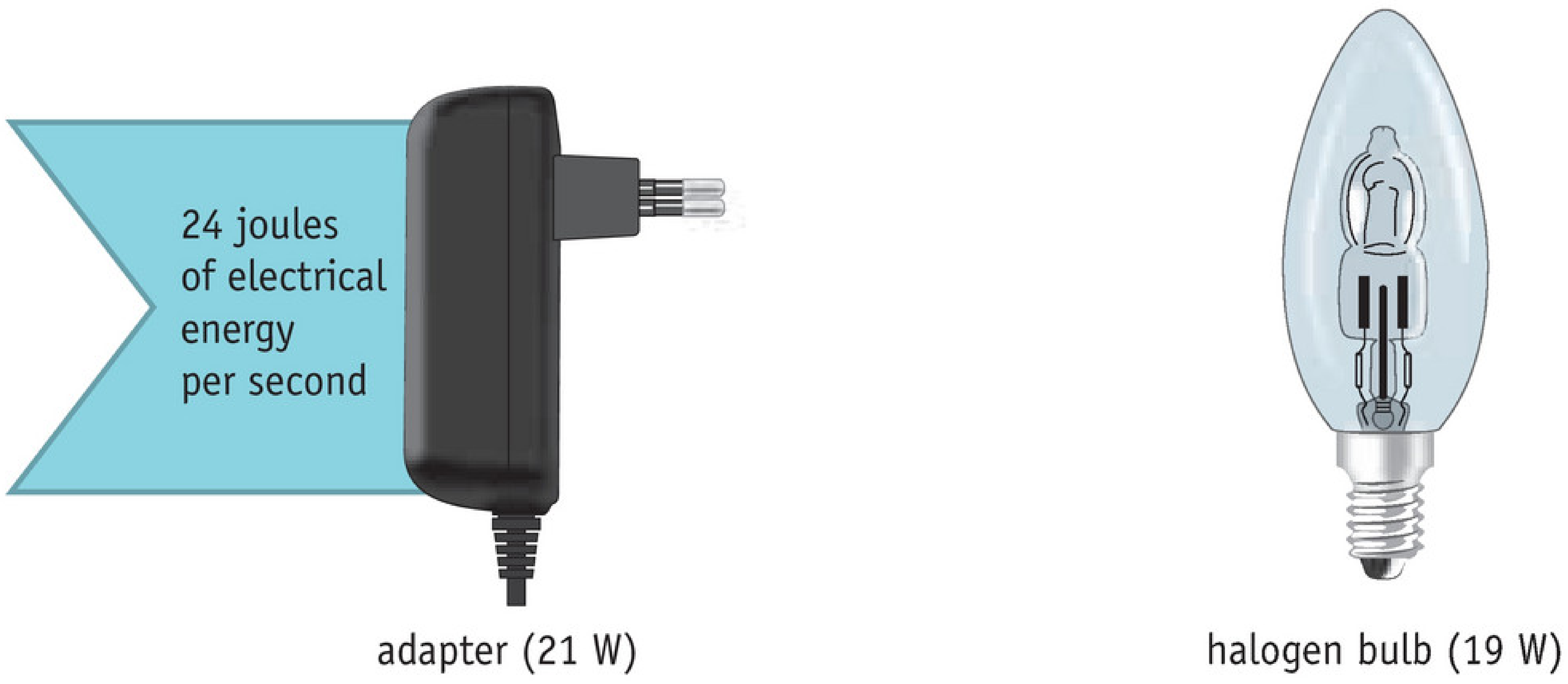


figure 7 The energy flow diagram for a mains adapter.

d The efficiency of the bulb is 25%.
Draw the energy flow diagram for the bulb and adapter combined in figure 7. Explain what you have drawn.

e Calculate the efficiency of the adapter and the bulb together.

6 A combined heating and hot water boiler burns 0.30 m^3 of natural gas in 10 minutes. In that time, 28 litres of water are heated from 15°C to 85°C.

a Calculate the amount of heat released by the combustion of the natural gas.

b Calculate the amount of heat taken up by the water.

c Calculate the efficiency of the combined boiler.

★ 7 A solar panel captures the most radiant energy when sunlight falls perpendicularly onto it. A maximum of 1.0 kW/m^2 of incoming irradiation can be absorbed in the Netherlands.

a At what time of the year and at what time of the day is the power absorption the highest?

b The power absorbed is usually a lot lower than 1.0 kW/m^2.
List two causes of this.

c A solar panel has a surface area of 8.0 m^2 and an efficiency of 15%.
Calculate the maximum electrical power (in kW) that the solar panel can produce.

d According to the Royal Netherlands Meteorological Institute (KNMI), the sun shines for about 1500 hours per year in the Netherlands. That is enough for an annual yield of 95 kWh of electrical energy per m^2 solar panel.
Use this information to calculate the average power absorbed per m^2.

8 An electric bottle warmer has a power rating of 80 W. It takes 8.5 minutes for the temperature of the 200 g of water in the baby's bottle to rise from 7°C to 37°C.

a Calculate the efficiency of the bottle warmer. Show all your calculation steps.

b Think of two reasons for this low efficiency.

9 Figure 8 shows you part of a brochure about heat pump dryers.

a List two arguments in favour of choosing a heat pump dryer.

b The cotton drying programmes of the heat pump dryer and the condenser dryer take almost equally long.
Explain which of the two tumble dryers has the higher power consumption.

c What method of drying your laundry is even more environmentally friendly than a heat pump dryer like this?

Heat pump dryers: extra efficient!

Tumble dryers are a blessing in a rainy country like the Netherlands, but they gobble up a lot of electricity. As your energy bill will soon tell you. To help reduce this problem, a heat pump dryer has been developed that is very economical in its energy consumption. If you use it for the average of four loads dried a week, it will save you two thirds of the energy costs per year compared to a condenser dryer.

figure 8 Advertisement for tumble dryers.

Test what you know with *Test yourself*.

PLUS USING RESIDUAL HEAT USEFULLY

10 All the houses in a new neighbourhood are often connected up to district heating.

a Explain why electricity is used for cooking in these houses instead of gas.

b A law was passed in 2014 that states (among other things) how much district heating may cost.
Explain why it is important to have legislation about this.

c Explain why the power station that provides district heating must still build another system to dispose of waste heat using coolant water.

11 A swimming pool in Aalsmeer is heated with industrial residual heat.

a Make an estimate to calculate how much energy is needed to heat the water of a swimming pool (a competition pool of 50 × 25 × 2.0 m) from 15 °C to 27 °C.

b Gas costs € 0.75 per m^3. Burning 1.0 m^3 gas supplies 32 MJ of energy.
Calculate how many m^3 gas are saved now that industrial residual heat is being used to heat the pool (Exercise a). How much is that in euros?

c Electrical energy costs € 0.23 per kWh.
How much money would heating the pool (Exercise a) with electrical energy cost?

d Use your answers in Exercises (a), (b) and (c) to explain why using residual heat for a swimming pool can be a nice solution.

Experiments

EXPERIMENT 1 THE SPECIFIC HEAT OF WATER

30 minutes

Introduction
The amount of heat required to increase the temperature of 1 g of any substance by 1 °C is called the specific heat of that substance.

Purpose
You are determining the specific heat of water.

Requirements
- ☐ calorimeter or insulated glass beaker (500 mL) with a lid
- ☐ thermometer
- ☐ immersion coil
- ☐ measuring cylinder
- ☐ stopwatch

Doing the experiment and writing it up
Measuring
- Put 500 mL water (measured as precisely as possible) into the glass beaker.
- Place the immersion coil in the water, but do not turn it on yet. Put the lid on the glass beaker (figure 1).
- Measure the initial temperature of the water.
- Connect up the immersion coil. Measure how long it takes to raise the temperature of 500 mL of water by 20 °C.

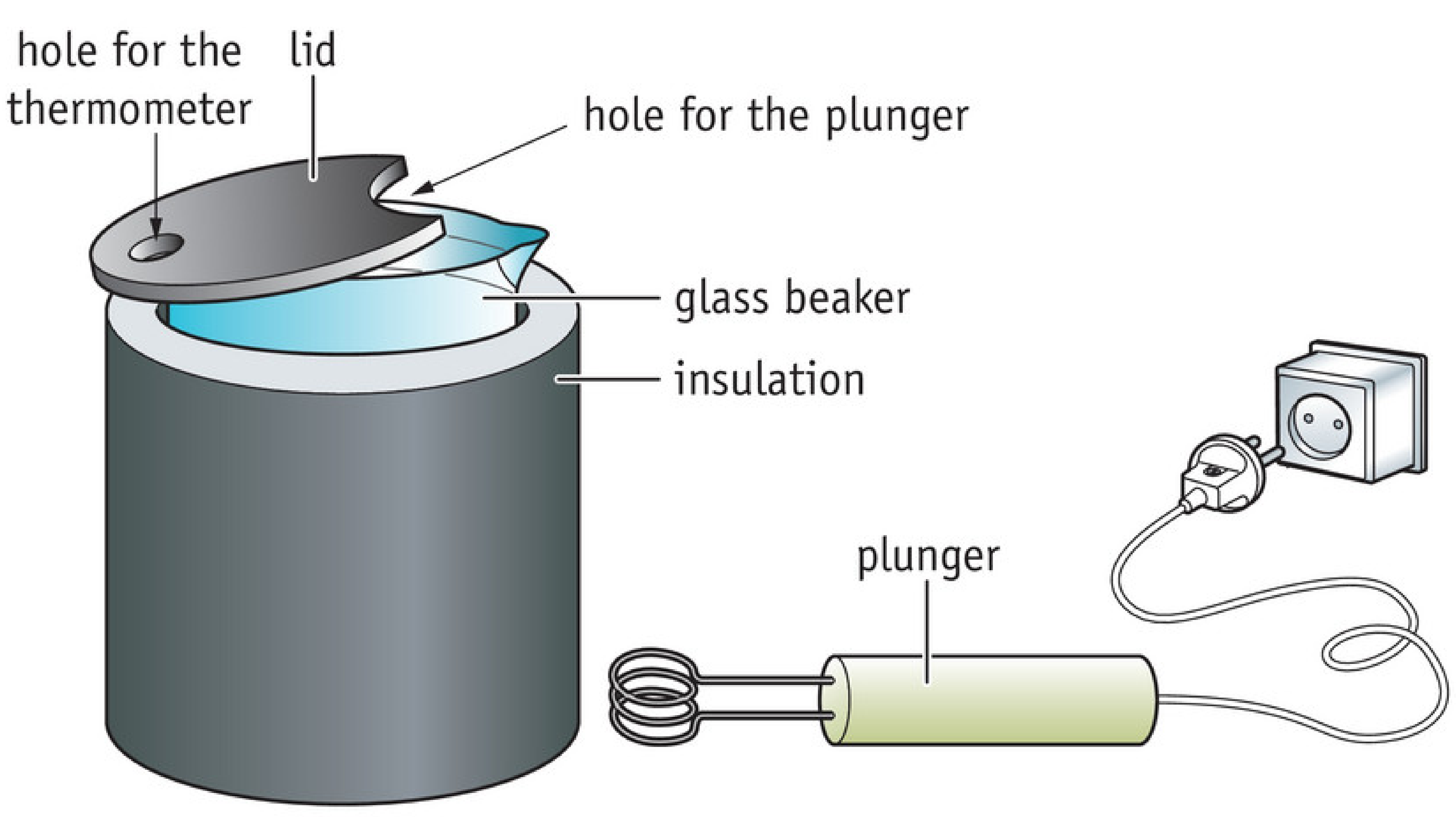


figure 1 The setup for Experiment 1.

1 Make a note of the power rating of the immersion coil, the starting temperature and the time required.

....

....

....

....

- After doing the experiment, take the plug out of the socket straight away.

Writing up

2 Use the formula $E = P \cdot t$ to calculate how much heat the immersion coil has provided.

....

....

....

3 Calculate the specific heat c of water using the formula $Q = c \cdot m \cdot \Delta T$.

....

....

....

4 Compare your result against the value given in Section 2.
How big is the difference?

....

5 Explain why the experiment that you carried out will probably give a value for the specific heat that is too high.

....

....

....

....

6 How could you determine the specific heat of water more accurately? Describe what you would have to change in the experiment to achieve this.

....

....

....

....

....

EXPERIMENT 2 THE EFFICIENCY OF A TEA LIGHT

30 minutes

Introduction

You can use a small candle such as a tea light to heat water. Part of the heat from the candle then ends up transferred into the water. Another fraction of the heat is lost. The efficiency of this form of heating is therefore clearly not 100%. But how much is it, actually? You are going to research that in this experiment.

Purpose

The question you are studying is:
What is the efficiency when you heat water using a tea light?

Requirements

- ☐ tripod
- ☐ ceramic triangle
- ☐ 100mL glass beaker
- ☐ measuring cylinder
- ☐ thermometer
- ☐ scales
- ☐ tea light
- ☐ matches
- ☐ a fire-resistant object that the tea light can be put on

Doing the experiment and writing it up

Preparation

A burning candle loses weight as it burns. This is because the combustion products (water vapour and carbon dioxide) are gaseous and end up spread out through the classroom. By weighing the candle before and after the experiment, you can determine how many grams of fuel have been burned.

Measuring

- Determine the initial mass of the tea light (candle).
- Put 50 mL water in the glass beaker.
- Measure the temperature of the water.

1 Make a note of the initial mass and the initial temperature.

....

....

- Set the experiment up as shown in figure 2. Light the candle.
- Stir occasionally with the thermometer.
- Measure the temperature of the water again after six minutes.
- Blow the tea light out carefully.
- Determine the mass of the candle again.

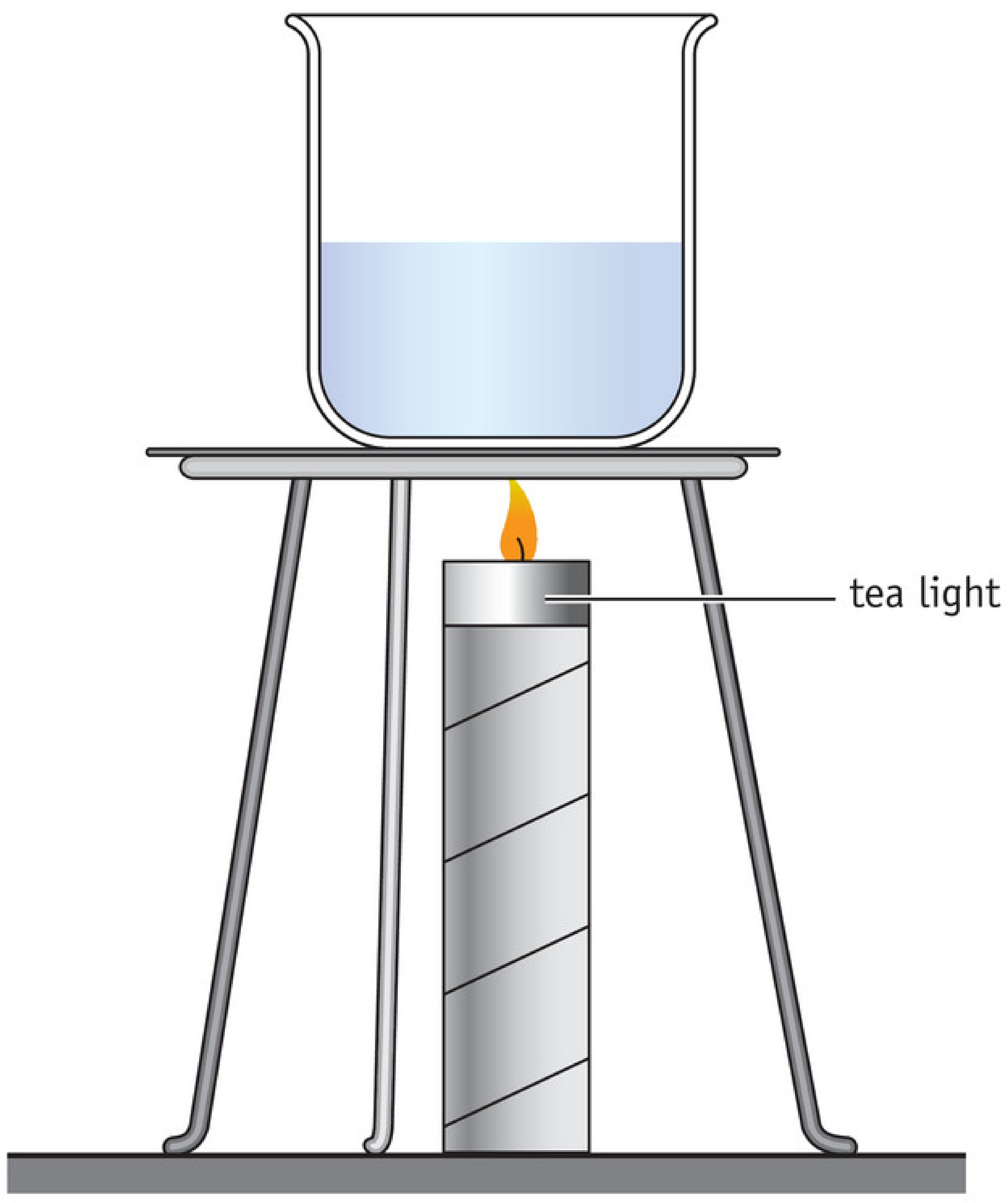


figure 2 The setup for Experiment 2.

2 Make a note of the final mass and the final temperature.

....

....

Writing up

3 Every 1.0 g of the tea light that is burned gives 40 kJ of heat.
Work out how much heat the tea light has provided.

....

....

....

4 Look in the theoretical section to find the specific heat of water.
Work out how much heat the water absorbed.

....

....

....

5 Use your answers to Exercises 3 and 4 to calculate the efficiency.

....

....

....

6 Compare the value you got for the efficiency against the values your classmates got.
Why did everyone get a different value?

....

....

....

....

7 How could you improve the efficiency of the tea light?

....

....

....

....

EXPERIMENT 3 THE VOLTAGE OF A SOLAR PANEL

45 minutes

Introduction

A solar panel gives the greatest voltage (and the most electrical energy) when it is precisely facing the sun. If the direction is not ideal, the voltage will be lower. An energy company wants to tell its customers exactly how the direction affects the output of the solar panels. In this task, you are the researcher who has to gather the data they need.

Purpose

How much lower is the voltage? You are going to research that in this experiment. The question you are studying is:
What is the relationship between the direction a solar panel is facing and the voltage that it generates?

Requirements

For this experiment, you have to think up for yourself what practical equipment you will need.

Doing the experiment and writing it up

- Think about how you can give the most reliable answer to the question. What is your test setup going to look like; what exactly are you going to measure; how will you make sure that the measurements are repeatable (and can therefore be verified)?

1 Make a work plan for this study.
- The work plans will be discussed with the rest of the class in the next lesson. If necessary, you can make improvements to your own work plan after that.
- Then carry out the experiment.

2 Note down all the measurements, calculations and results in your exercise book.
- Your teacher will tell you whether or not you have to write up a report on this experiment.

The following experiment can be found in the online learning environment. Your teacher decides whether the experiment will be carried out.

EXPERIMENT 4 CONDUCTION OF HEAT

15 minutes

Introduction

You are going to investigate how well various substances conduct heat.

Storing sustainably produced energy

Now that more and more electrical energy is being generated with solar panels and wind turbines, many researchers and businesses are working on smart solutions for storing this sustainably produced energy. The first mega-batteries have already been installed in Australia and the United Arab Emirates. A lot of effort is being put into realizing the first test facility for making solar fuels.

The production of sustainable electricity depends on the availability of sun and wind. When there is no wind and it is cloudy, the power supply can be threatened and power stations that run on fossil fuels are switched on. However, too much wind can also cause problems. On Christmas Day 2015, the wind in Eastern Germany was suddenly a lot stronger than forecast. At that moment, the wind turbines in the area supplied 12 GW, three times as much as the East Germans themselves used. The surplus electricity had to be transported to other areas quickly via high voltage power lines to prevent a power outage in a large area due to overloading. That is why at that time the price for electricity on the trading market dropped from € 40/MWh to a negative price of −€ 120/MWh. Those who could use up a lot of electricity at that time were paid! A very accurate weather forecast is becoming increasingly important, preferably on a timescale of minutes.

One way to prevent shortages and surpluses in the energy supply is to store sustainable energy. Large-scale storage of electrical energy is an important aspect of the energy transition.

MEGA-SIZED BATTERIES

In a large part of South Australia, there were several power cuts in 2016 and 2017 caused by storms and heat. The Australian government decided to do something and asked companies to come up with sustainable solutions for storing at least 100 megawatt-hours (MWh) of electrical energy (the capacity). Tesla, the same company that is well-known for its electric cars, promised to get the job done within one hundred days. Tesla got the job and constructed the Powerpack within three months, a mega-battery with a power of 100 MW and a capacity of 129 MWh. The Powerpack has

been installed at a wind farm near Jamestown (figure 1). It is the largest lithium-ion battery on the planet and it is charged up when too much electrical energy is produced. The battery then supplies energy when demand is higher than the production from the wind turbines of the wind farm. In the warm climate of South Australia, the mega-battery does have to be cooled to extend its lifespan.

figure 1 Tesla's Powerpack lithium-ion battery in South Australia.

This battery farm is a huge success. In the first four months of 2018 it ensured that the costs for dealing with power cuts fell dramatically. A fossil fuel power station that was used for relieving shortages of renewably generated electricity became redundant. Moreover, the mega-battery can be deployed more quickly than a power station and the battery farm does not emit any carbon dioxide. After a year, 60% of the total cost of 66 million dollars for the construction of the Powerpack had been recovered.

In 2019, a mega-installation of batteries was built in Abu Dhabi, with a total power of 108 MW and a capacity of 648 MWh. This installation consists of sodium-sulphur batteries. These are made of cheap raw materials but are quite a bit bigger than lithium-ion batteries. Figure 2 shows sodium-sulphur batteries that can be charged and discharged indefinitely without reducing the lifespan, as long as they are heated up to 300 °C.

SUSTAINABLE KEROSENE

The energy transition has progressed quite a bit further in Germany than in the Netherlands. In 2019, more than 50% of the electrical energy there was generated sustainably by wind turbines and solar panels. That seems a lot, but only twenty per cent of all the energy that is used is electrical. It is important that we also work on sustainable forms of fuel for cars, trucks, ships and aircraft.

figure 2 Large sodium-sulphur batteries.

Cars can run on electrical energy and you can see this on the road more and more. Large aircraft that run on solar panels or batteries, however, only exist in science fiction as yet. That is why a plan was made for producing sustainable kerosene for Schiphol. If you can convert carbon dioxide from the air into kerosene using sustainable electricity, aircraft flights could become CO_2-neutral. This is technically difficult, but capturing carbon dioxide from industrial applications is possible. If you do that, the industry no longer produces carbon dioxide that disappears into the atmosphere. That only happens later when the aircraft flies. This step has not used fossil fuels, so the carbon dioxide emissions are reduced by 50%.

"This fast technology can greatly improve the stability of the electricity grid."

figure 3 The blast furnaces in Velsen.

In 2018, the company Quintel Intelligence calculated that the total amount of carbon dioxide that the blast furnaces in Velsen (figure 3) emit (9 megatons per year, where 1 ton is 1000 kg) is enough to make sustainable kerosene for half of all the aircraft at Schiphol (figure 4). Electricity and hydrogen are also required, which are produced by wind farms in the North Sea. A partnership of researchers and companies wants to build a test facility for this. This will allow the various steps in the production process to be studied and optimized. A genuinely sustainable kerosene factory could then start production in 2030. Using sustainable kerosene will hardly make plane tickets any more expensive. This research can make the Netherlands a front-runner in the development of sustainable fuels.

Solar fuels

Fuels that are produced using sustainable electricity are known as solar fuels. If you use carbon dioxide from the atmosphere and water to make a fuel, these are also the products that are released when burning the fuel. And so the cycle is complete. Making kerosene as solar fuel is done as follows:

1 Electrolysis: water is split into hydrogen and oxygen using renewable electrical energy (the oxygen is not used). In theory, it requires 144 MJ to make 1.0 kg of hydrogen this way. In practice, the efficiency of this process in the best systems is 70% at most.
2 Collecting carbon dioxide. Removing carbon dioxide from the air requires a lot of energy. It is easier to extract the gas from industrial plants such as blast furnaces. Capturing 1.0 kg carbon dioxide will then require 0.9 MJ.
3 Converting carbon dioxide into carbon monoxide using hydrogen. Making 1.0 kg carbon monoxide from 1.6 kg carbon dioxide requires 2.2 MJ.
4 Kerosene is made using carbon monoxide and hydrogen. This is already happening on a large scale.

figure 4 In the future, this aircraft can be refuelled with sustainably produced kerosene.

EXERCISES

1 Table 1 gives various bits of information about lithium-ion batteries.

table 1 Information about lithium-ion batteries.

lithium-ion battery	
source voltage	3.6 to 3.7 V
charging/discharging efficiency	80-92%
self-discharge	5-10% per month
capacity loss after 1 year (25 °C)	2-20%
capacity loss after 1 year (40 °C)	15-35%

a Use the information in figure 1 to explain why lithium-ion batteries are unsuitable if you want to store electrical energy for three months.

b The term "charging/discharging efficiency" indicates what the efficiency is of the storage of electrical energy in a lithium-ion battery.
Use the information in table 1 to explain why the efficiency of Tesla's brand-new Powerpack in South Australia will be less than 92%.

2 Write down advantages and disadvantages of the sodium-sulphur batteries in Abu Dhabi compared to the Powerpack in South Australia.

3 The production of 1.0 kg kerosene from 2.0 kg carbon monoxide and 0.30 kg hydrogen requires 0.9 MJ.

a Calculate the amount of energy required for the production of 1.0 kg kerosene.
First, calculate the energy required for each of the four steps in making sustainable kerosene.

b The wind farm near Ijmuiden that will provide sustainable electrical energy supplies of 10 GW on average.
How many kilograms of kerosene can you make with this per second?

c How much carbon dioxide can be converted per second using sustainable energy from the wind farm? How much is that per year?

d The blast furnaces in Velsen emit 9.0 megatons of carbon dioxide per year.
How much of the power of the 10 GW wind farm is used at most for making kerosene?

e In 2018, the total power of all the systems that generate electricity in the Netherlands was about 30 GW.
Based on this information and your answer to Exercise (d), give your opinion on the feasibility of making kerosene with the energy from this wind farm.

Course material overview

3.1 ENERGY SOURCES

REMEMBER

- An energy source is anything that can provide a usable type of energy.
- Energy sources that are used in the Netherlands are fossil fuels, biomass, wind, nuclear fission, solar power and geothermal heat.
- The ideal energy source is inexhaustible, always available, environmentally friendly and cheap.
- The transition from non-sustainable energy sources to climate-neutral energy sources is called the energy transition.
- The energy transition has four characteristics: sustainable energy sources, efficient energy management, large-scale energy storage and local production of energy.

CONCEPTS

biomass
Material originating from plants and animals that is used as an energy source.

chemical energy
Energy in fuels.

energy source
Anything that can provide a usable type of energy.

energy transition
The transition from non-renewable energy sources to sustainable, climate-neutral energy sources.

fossil fuel
A fuel such as petroleum, natural gas or coal that originated from the remains of plants and animals.

geothermal heat
Heat from the deeper layers inside the Earth.

heat exchanger
Device in which heat is transferred from one substance to another.

kinetic energy
Energy that moving objects have as a result of the fact that they are moving.

radiant energy
Energy from the radiation that an object emits, such as energy from sunlight.

solar cell
The part of a solar panel that converts the radiant energy of sunlight into electrical energy.

solar collector
Device that converts the radiant energy of sunlight into heat, which heats water.

wind turbine
Modern windmill that produces electrical energy.

3.2 HEATING

REMEMBER

- In an energy flow diagram, you show what type or types of energy a device consumes and what type or types of energy it releases. The amount of energy is always equal before and after conversion.
- Heat is a lower-quality type of energy than chemical energy or electrical energy, for instance.
- The temperature depends on the average speed at which molecules move. The faster the molecules are moving, the higher the temperature.
- You can calculate the amount of energy required to heat a quantity of a substance by a certain temperature difference using the formula $Q = c \cdot m \cdot \Delta T$, where c is the specific heat of that substance.

CONCEPTS

calorimeter
Device that lets you measure how much heat is required to heat a certain amount of water.

electrical energy
Energy supplied by voltage sources, such as batteries and dynamos.

energy conversion
Process in which one type of energy is changed into another type.

energy flow diagram
Schematic representation of an energy conversion.

heat
Type of energy that can increase the speed of movement of the molecules in a substance.

heat source
Device that supplies heat.

law of conservation of energy
The rule that states that no energy is lost in an energy conversion.

quality
Value, worth. The quality of a type of energy defines how easy it is to use that type of energy.

quantity
A measurable amount.

specific heat
The amount of heat required to increase the temperature of 1 g of a specific substance by 1 °C.

3.3 INSULATING

REMEMBER

- A house loses heat to the surroundings if the temperature indoors is higher than the temperature outdoors.
- Heat loss can take place by conduction, convection and radiation.
- You can reduce heat loss from a house by reducing or preventing conduction, convection and radiation.
- In a dynamic equilibrium between heat production and heat loss, the balance is re-established whenever the heat production or the heat loss changes.
- You can calculate the amount of heat that disappears through a wall per second using the formula: $Q_w = U \cdot A \cdot \Delta T$
- You can insulate a house by using HR++ or HR+++ glass instead of single or double glazing. You can insulate walls, roofs and floors by applying materials that contain a lot of stationary air.

CONCEPTS

conduction
Process in which heat spreads through a stationary substance.

convection
Process in which a liquid or gas starts to move and so takes the heat with it.

dynamic equilibrium
A balance that is re-established after every change, such as the balance between heat production and heat loss in a house.

insulation
Measures that you can take to minimize heat loss (from a home).

radiation
Process in which radiant heat spreads (as small packets of radiant energy).

3.4 EFFICIENCY

REMEMBER

- You can reduce the energy consumption of a device by reducing the power of the device or by reducing the length of time the device is on.
- By making energy flow diagrams of two devices with a comparable performance, you can compare the energy consumption of the devices.
- You can calculate the efficiency of a device by comparing the energy that the device converts against the energy that is used usefully. Expressed as a formula:

$$\eta = \frac{E_{\text{useful}}}{E_{\text{tot}}} \cdot 100\%$$

- You can calculate the efficiency of a device by comparing the power rating of the device against the power that is available for use. Expressed as a formula:

$$\eta = \frac{P_{\text{useful}}}{P_{\text{tot}}} \cdot 100\%$$

- You can calculate the energy that burning a certain amount of fuel provides by multiplying the calorific value by the amount of fuel.

CONCEPTS

calorific value
Heat that is released when a certain amount of fuel is burned.

efficiency
The amount of energy that is usefully usable as a percentage of the total energy that is converted.

Go to the *Flash cards* and the *Diagnostic test*.

Skills

GATHERING AND PROCESSING DATA

Physics is often about both knowledge (what you know) and skills (what you can do). The skills include aspects such as building experimental setups, collecting the measurement data, performing calculations and drawing graphs. This part of the book gives you a summary.

1 Doing research

Research starts with a question that you are studying. You make a plan to find the answer, and then you carry out that plan yourself. You do this step by step.

Step 1 **Think of a study question.**
Sometimes this will already be stated in the exercise. In that case, all you have to think about is how you can answer the question. Sometimes you are expected to think up a study question of your own. Don't be content with it too quickly: you must have some idea of how you could answer your question. Formulate your study question as precisely as possible before you go any further.

Step 2 **Make a working plan.**
In your working plan, you should write down:
- what variables you are going to measure;
- what materials and equipment you will need;
- what experimental setup you are going to construct (make a drawing);
- what measurements you are going to make;
- which formulae you are going to use (if applicable).

Step 3 **Doing the experiment and writing it up.**
You construct the experimental setup and use it for carrying out the measurements as planned. After each measurement, you make a clear note of the measured values, for example in a table. After you have finished, you work out the measurements in more detail, for instance by drawing a graph or doing calculations. If necessary, use the other skills for this too.

Step 4 **Drawing conclusions.**
If everything has gone as intended, you are now able to draw your conclusions. Taken together, the conclusions provide the answer to the study question. A conclusion is not a summary of the measurement results: it is something that you can derive (conclude) from the measurements. You should also think about what you could have done better in your research.

Step 5 **Writing a report.**
Finally, you make a report of your research. See the skills section on '*Writing a report*'.

2 Working with variables and units

A variable is something that you can measure. Example of variables are mass, force, resistance and time. To be able to measure a variable, you need units to express it in. You measure mass in kilograms, force in newtons, resistance in ohms and time in seconds.

The size of a unit is often not convenient for the variable you want to measure. In that case, you can put a multiplier prefix before the unit. Instead of saying that the thickness is 0.0003 metres, you would write "The thickness is 0.3 mm."

You can always replace these prefixes with a power of ten (and vice versa). Instead of saying that insulating the pipes would save 4.8 GJ of heat, you could also write "Insulating the pipes saves you $4.8 \cdot 10^9$ J of heat." See table 1.

table 1 Prefixes and their meanings.

prefix	abbreviation	meaning	example
giga	G	10^9	1 GJ = 10^9 J
mega	M	10^6	1 MW = 10^6 W
kilo	k	10^3	1 kN = 1000 N
hecto	h	10^2	1 hPa = 100 Pa
deca	da	10^1	1 dam = 10 m
deci	d	10^{-1}	1 dL = 0.1 L
centi	c	10^{-2}	1 cm = 0.01 m
milli	m	10^{-3}	1 mΩ = 0.001 Ω
micro	µ	10^{-6}	1 µg = 10^{-6} g
nano	n	10^{-9}	1 ns = 10^{-9} s

Sometimes there are several units that are in use for the same variable. Think of electrical energy, which can be in joules (J) or kilowatt-hours (kWh), or a speed in metres per second (m/s) or kilometres per hour (km/h). In that case, you sometimes have to convert a value from one set of units to another.

EXAMPLE EXERCISE 1

According to a consumer organization, an average family in the Netherlands uses about 300 kWh of electrical energy per year.
What is that in joules?

1 kWh = $3.6 \cdot 10^6$ J

300 kWh = $300 \times 3.6 \cdot 10^6 = 1.08 \cdot 10^9$ J (or 1.08 GJ)

EXAMPLE EXERCISE 2

A car manufacturer states that the top speed of its high-performance model is 255 km/h.
What is that in m/s?

1 m/s = 3.6 km/h

$$255 \text{ km/h} = \frac{255}{3.6} = 71 \text{ m/s}$$

3 Working with powers of ten

In physics, you often have to deal with numbers that are extremely large or extremely small. There is a handy way of writing numbers like those. For large numbers, you use positive powers of 10. For small numbers, you use negative powers of 10.

positive powers	**negative powers**
$10^1 = 10$	$10^{-1} = 1/10 = 0.1$
$10^2 = 10 \times 10 = 100$	$10^{-2} = 1/10 \times 1/10 = 1/100 = 0.01$
$10^3 = 10 \times 10 \times 10 = 1000$	$10^{-3} = 1/10 \times 1/10 \times 1/10 = 1/1000 = 0.001$
etc.	etc.

If you want, you can replace the power of 10 with a prefix. Instead of saying that Instead of writing “The capacity of the power plant is $4.75 \cdot 10^8$ W”, you can also write “The capacity of the power plant is 475 MW.” Work it out:
$4.75 \cdot 10^8$ W = $475 \cdot 10^6$ W = 475 MW (M = 10^6)

EXAMPLE EXERCISE

The nuclear power plant in Gravelines (in France) has an electrical output of 5460 MW. In practice, only 75% of this capacity is actually delivered. On average, 25% of the capacity is not available, mostly because of maintenance.
Calculate how many kWh of electricity the nuclear power station produces in one year.

75% of 5460 MW = 4095 MW
P = 4095 MW = $4095 \cdot 10^6$ W = $4095 \cdot 10^3$ kW
$t = 365 \times 24 = 8760$ hours

$$\begin{aligned} E &= P \cdot t \\ &= 4095 \cdot 10^3 \times 8760 \\ &= 36 \cdot 10^9 \text{ kWh} \end{aligned}$$

The power station produces 36 billion kilowatt-hours of electrical energy every year.

table 2 Examples of powers of 10 from nature.

	height (m)	mass (kg)	time (s)
10^{-10}	diameter of an atom		
10^{-9}			
10^{-8}	diameter of the smallest virus		
10^{-7}		mass of a sand grain	
10^{-6}	diameter of a bacterium	mass of a raindrop	
10^{-5}	diameter of a red blood cell		
10^{-4}	thickness of paper	mass of a fly	duration of a lightning flash
10^{-3}			
10^{-2}	thickness of a finger	mass of a mouse	
10^{-1}			reaction time of a human
10^{0}	height of a human	mass of a bag of sugar	time between two heartbeats
10^{1}			world record for the 100 m sprint
10^{2}	length of a supertanker	mass of a human	
10^{3}		mass of a car	a quarter of an hour
10^{4}	maximum depth of the oceans		
10^{5}		mass of a jumbo jet	one day
10^{6}	diameter of the moon		
10^{7}	diameter of the earth		one year
10^{8}	Earth-Moon distance	mass of a supertanker	
10^{9}			lifespan of a human
10^{10}			
10^{11}	distance from the Earth to the Sun		age of the pyramids
10^{12}			modern humans present on Earth

4 Working with measuring instruments

You use all kinds of measuring instruments in physics. To measure things properly, you have to take it step by step.

Step 1 **Determine what measuring instruments you need.**
For an experiment, you will want to answer a question such as:
Is the electrical rating stated on this appliance correct?
You know that you can determine the electrical power (the rating) using the formula $P = U \cdot I$. That means that you have to measure the voltage (U) and the current (I). So you need two measuring instruments: a voltmeter and an ammeter.

Step 2 **Connect up the measuring instrument.**
Ammeters and voltmeters have to be connected up correctly: an ammeter in series with the device, a voltmeter in parallel (figure 1).
For direct currents and voltages, the direction the current is flowing in is also important. You have to connect the plus terminal of the meter to the positive terminal of the voltage source and the minus to the negative terminal. The plus terminal is usually a red jack socket and the minus is usually black (see figure 2).

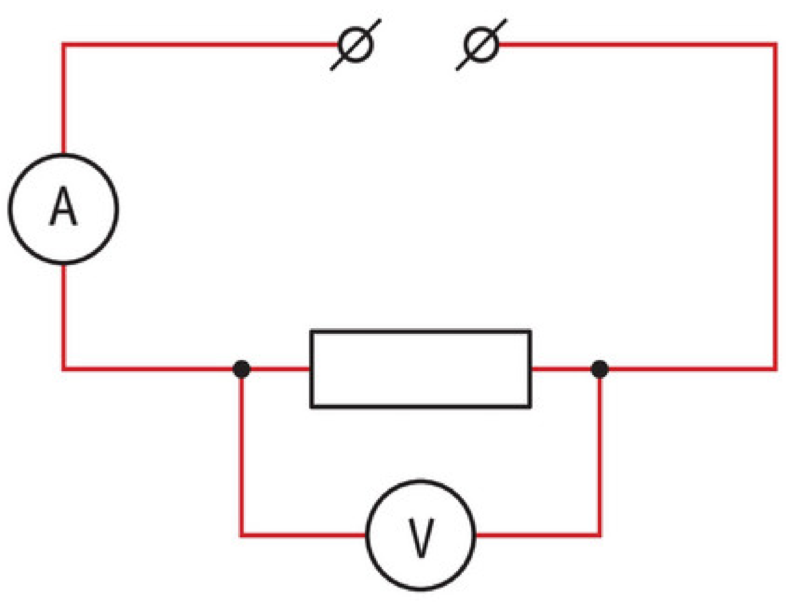


figure 1 How to connect up a voltmeter and ammeter.

figure 2 What is the current?

Step 3 **Select the correct measurement range.**
Ammeters and voltmeters often have more than one measurement range. The ammeter in figure 2, for instance, has three measurement ranges: 0 to 5 A, 0 to 0.5 A and 0 to 0.05 A. You can find out which measurement range you should be using as follows:

- Make a test measurement using the greatest measurement range.
- This lets you see roughly how big the current or voltage is.
- Then choose the smallest measurement range in which the meter can still be read.
- The smaller the measurement range you use, the more accurate the measurement result will be.

Step 4 **Read the measuring instrument.**

Many measurement instruments have a graduated scale. When you are taking a reading from a measuring instrument like this, you first have to determine how much each mark on the scale represents. Then you read the value off as accurately as possible.

In the ammeter in figure 2, for example, it goes like this:

- I have used the measurement range from 0 to 0.5 A.
- Between 0.3 and 0.4 A, there are ten gaps (nine other marks).
- Each mark is therefore equal to $\frac{0.1}{10}$ = 0.01 A.
- The needle is pointing to the sixth mark.
- The current is therefore 0.36 A.

5 Working with formulae

Physics often requires you to do calculations. You should take a step-by-step approach to this.

Step 1 **Read the exercise.**
Read the instructions and estimate roughly what the result should be. In the worked example, it asks you how long a kettle will take to boil one cup of water. You know that you will have to wait a few tens of seconds or a minute or so. If you get an answer of a couple of seconds, that is clearly too little. Similarly, five minutes is clearly too long.

Step 2 **Write down the data.**
Convert all the data into letter symbols and numbers, and make a note of it. A data item such as "44 kJ of heat" should for example be written as: $E = 44\text{ kJ} = 4.4 \cdot 10^4\text{ J}$.

Step 3 **Write the formulae down.**
Some formulae can be written in different ways. Use the form that has the variable you want to calculate in front of the equals sign. So you write:

- $E = P \cdot t$ if you want to work out the amount of energy (E);
- $P = \frac{E}{t}$ if you want to calculate the power (P);
- $t = \frac{E}{P}$ if you want to calculate the time required (t).

Step 4 **Fill in the data.**

Step 5 **Do the calculation.**

Step 6 **Write down the result.**
The result is a number followed by a unit. The unit must match the data. If you give the power in watts (W = J/s) and the time in seconds (s), you will get the amount of energy in joules (J). See also *Rounding off results* in the Skills section.

Step 7 **Check the result.**
Compare the result against the estimate that you made at the start. You should also check that you did not make any calculation errors or mistakes when copying the numbers down.

EXAMPLE EXERCISE
Boiling water for a cup of tea requires 44 kJ of heat.
How long does a kettle of 1800 W take to supply this amount of energy?

given $E = 44\text{ kJ} = 4.4 \cdot 10^4\text{ J}$
$P = 1800\text{ W}$

required $t = ?$

working $t = \frac{E}{P} = \frac{4.4 \cdot 10^4}{1800} = 24\text{ s}$

6 Rewriting formulae

You often use formulae in physics. A formula can be written in more than one way. Sometimes one form will be handier and sometimes another will be better. That does not mean that you have to remember all the different forms. If you remember just one form, you can quickly work out the others from it. This is known as ‘rewriting’ the formula.

There are two mathematical methods you can use for rewriting formulae: cross-multiplication and the balancing method. Taks this formula, for example: $v = \frac{s}{t}$

Suppose that you want to use this formula to calculate the time t. You can rewrite the formula like this:

Method 1: Cross-multiplication

To do this, you first express both sides as fractions: $v = \frac{s}{t} \rightarrow \frac{v}{1} = \frac{s}{t}$, because $\frac{v}{1} = v$

Cross-multiply by the variables underneath:

$\frac{v}{1} = \frac{s}{t} \rightarrow v \cdot t = s \cdot 1 \rightarrow v \cdot t = s$

Now divide both sides by v: $v \cdot t = s \rightarrow \frac{v \cdot t}{v} = \frac{s}{v}$

Simplify the result: $\frac{v \cdot t}{v} = \frac{s}{v} \rightarrow t = \frac{s}{v}$, because $\frac{v}{v} = 1$

Method 2: The balancing method

This involves always doing the same thing on both sides of the equals sign. The equals sign actually means that the same value is represented on both sides of it, for example $3 = 3$, or $\frac{6}{2} = \frac{3}{1}$ or $v = \frac{s}{t}$

You can multiply both sides by the same number. The values on either side of the equals sign will change, but they will still be equal to each other. For example: $\frac{6 \cdot a}{2} = \frac{3 \cdot a}{1} \rightarrow 3 \cdot a = 3 \cdot a$

The same is true when you divide both sides by the same number.

Now multiply both sides of $v = \frac{s}{t}$ by t: $v = \frac{s}{t} \rightarrow v \cdot t = \frac{s \cdot t}{t}$

Write $v \cdot t = \frac{s \cdot t}{t}$ as $v \cdot t = s$, because $\frac{t}{t} = 1$

Divide both side by v: $v \cdot t = s \rightarrow \frac{v \cdot t}{v} = \frac{s}{v}$

Write $\frac{v \cdot t}{v} = \frac{s}{v}$ as $t = \frac{s}{v}$, because $\frac{v}{v} = 1$

7 Rounding off results

The results of a calculation cannot be more accurate than the data that you used. This means that you often have to round off the results of a calculation. Otherwise, it gives the impression of being a very accurate result when it really is not.

In the example exercise, the voltage is 134 mV and the current is 1.9 mA. You can see that the voltage has been given to three significant figures and the current to two significant figures. This means that the current is a less accurate data item. You have to allow for that when rounding off.

You can use a simple rule of thumb for rounding off:

The result is given to the same number of significant figures as the least precise data item.

It will also be reckoned to be OK if the result has one more significant figure, though.

You must take special care with the zeroes when counting the number of significant figures:

- Zeroes at the start of a number do not matter when you are counting the number of significant figures: 25 cm has just as many significant figures as 0.25 m. The leading zero is only telling you about the magnitude of the number – it doesn't say anything about the precision. It is not a significant digit.
- Zeroes in the middle or at the end of the number do count towards the number of significant figures. If your height is given as 1.80 metres, the zero is making clear that your height was measured to an accuracy of 1 cm. So this zero is indeed saying something about the accuracy.
- Some more examples:
  - 2.0 has two significant figures, but 0.2 only has one significant figure;
  - 0.22 and 0.022 both have two significant figures;
  - 2.02 has three significant figures.

To round off correctly, you look to see the first digit that has to be dropped. If that is a 5 or more, you have to 'round up'. That means that the digit before it has to be increased by 1. If the digit you are dropping is 4 or less, you do not have to increase the digit before it.

If you have to give an answer to three figures:

- you round 2.345 to 2.35;
- you also round 2.354 to 2.35;
- you round 2.395 to 2.40;
- you also round 2.404 to 2.40;
- and so forth.

EXAMPLE EXERCISE

When there is a voltage of 134 mV across a resistor, the current through it is 1.9 mA. Calculate the resistance.

given U = 134 mV = 0.134 V
I = 1.9 mA = 0.0019 A

required R = ?

working $R = \frac{U}{I} = \frac{0.134}{0.0019} = 71\ \Omega$

Explanation

If you do the sum on a calculator, the answer you will get is 70.526316. The data item I = 1.9 mA has the fewest significant figures: two. You should therefore also give your answer to two significant figures. So you drop all the numbers after the 70. However, because the first digit that you are dropping is a 5, you have to increase the digit in front of it and the 0 becomes a 1. The correctly rounded result is therefore 71 Ω.

8 Working with tables and graphs

Many study questions are about the relationship between two variables. Take the following study question, for example:
What is the relationship between the extension of a spring and the force that is exerted upon it?
This question is about the relationship between the force and the extension.

To answer the question, you carry out a series of measurements. You hand weights on the spring, measuring how far it extends each time. You then note down the measurement results in a table. After completing the experiment, you show the measurement results from the table in a graph.

You make the graph as follows:

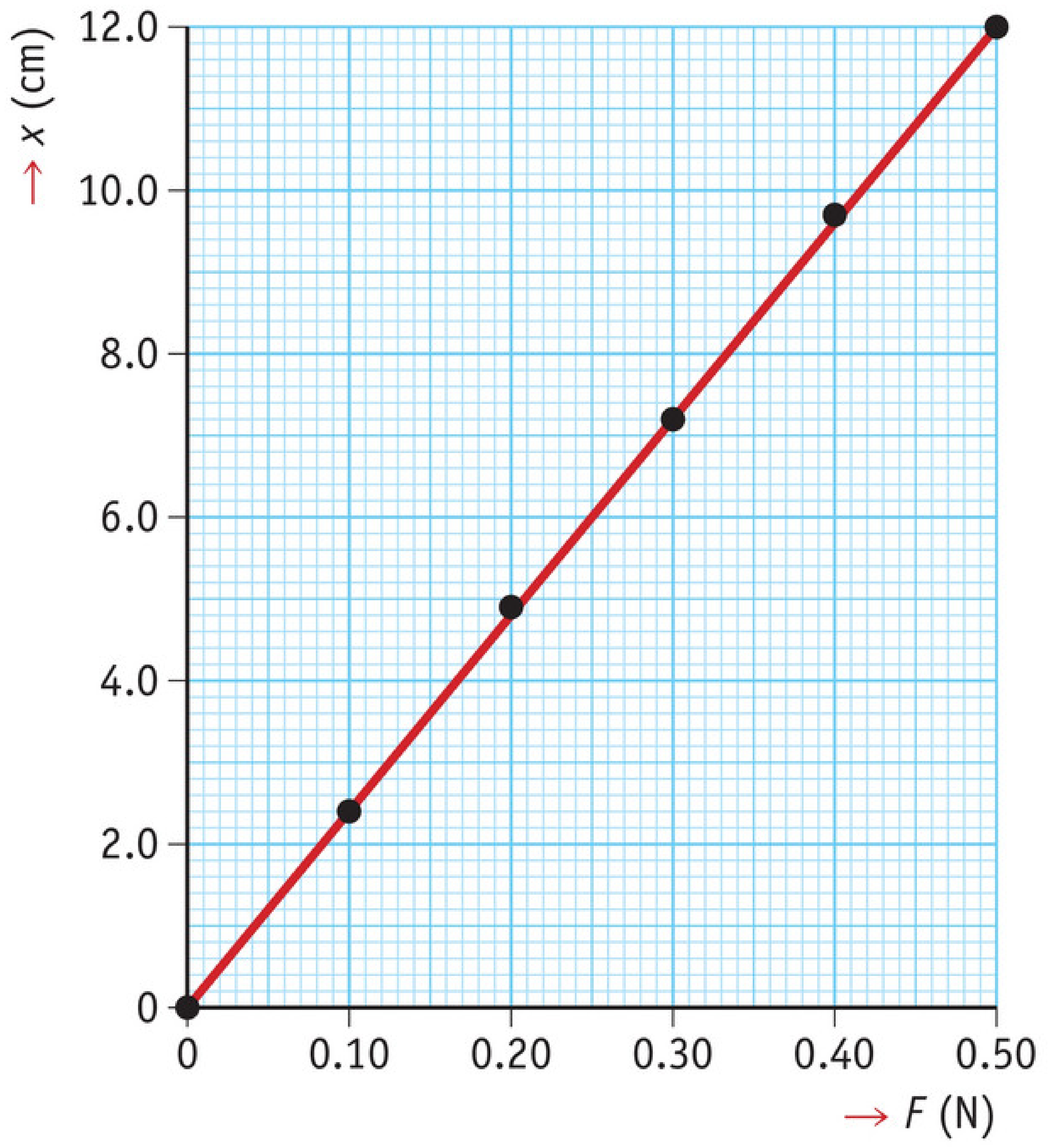


figure 3 A graph of extension against force.

Step 1 **Draw a set of axes.**

Step 2 **Label each axis with a variable and the corresponding units.**
For example, → *F* (N) and → *x* (cm).

Step 3 **Draw an appropriate scale along each of the axes.**
Make sure that the biggest numbers still fit on it.

Step 4 **Plot in the measurements as points.**

Step 5 **Draw in the lines.**
If all the points are on a straight line (or roughly on one), draw a straight line through them. If they are not, draw a smooth curve. Make sure that the line fits the points as well as possible, but never 'join the dots' one by one. It does not matter if the straight line or curve does not go precisely through all the measurement points.

9 Measuring relationships

Many study questions are about the relationship between two variables. Take the following study question, for example:
What is the relationship between the extension of a spring and the force that is exerted upon it?
In this question, the variables are the force (on the spring) and the extension (of the spring).

How can you measure this kind of relationship? A few hints:

Step 1 **First make a table that you can note the measurement results down in.**
Note the force on the left and the extension on the right.

Step 2 **Choose a step size for the variable in the left-hand column that is a convenient round number,**
for example the following values for the force (in N):
0.0 0.1 0.2 0.3 0.4 and so on.
That will make it easier to draw the graph later on.

Step 3 **Write the measured values down in the table: the force (in N) on the left and the extension (in cm) on the right.**

Step 4 **Make a graph using your measurements.**
The skills section on *Working with tables and graphs* tells you how to do that. Put the force along the horizontal axis and the extension on the vertical axis.

Step 5 **Compare your graph against figure 4.**

The figure shows you what your graph will look like:

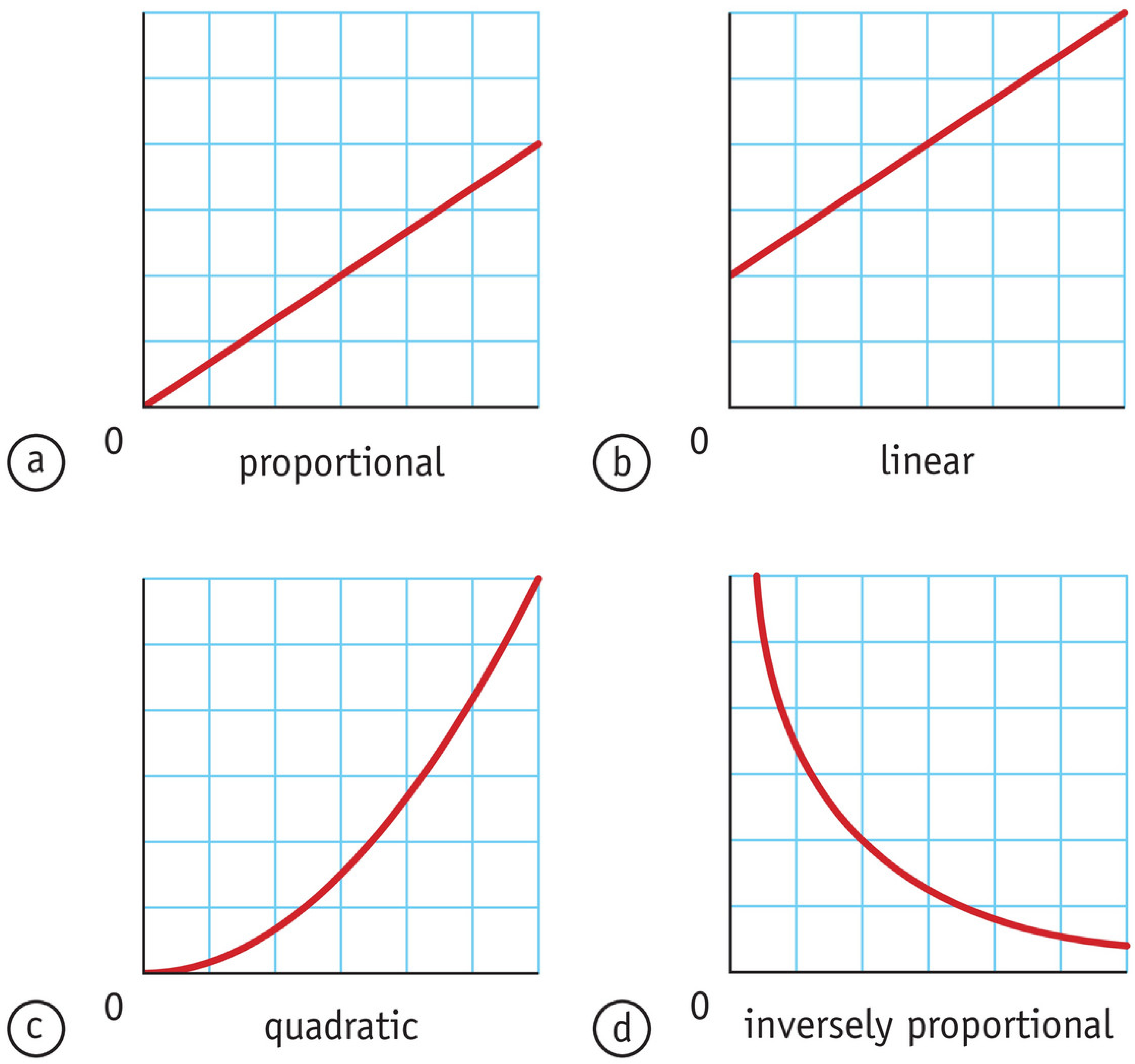
a if the relationship is proportional;

b if the relationship is linear;

c if the relationship is quadratic;

d if the relationship is inversely proportional.

figure 4 Four types of relationships.



The (u,F) diagram for a helical spring is a straight line through the origin (figure 3 in the skills section on *Working with tables and graphs*). This shows you that the relationship between the extension and the force is proportional for a helical spring.

10 Writing a report

Research has to be written up. In the report, you explain what happened during the experiment. Somebody who was not actually there must be able to understand exactly what happened.

Lay your report out like this:

Title page
This is where you can give the title of the report, the names of the pupils in your group doing the experiment, the name of your teacher and the date and year.

Section 1 Study question
This section is where you explain what question you want your study to answer.

Section 2 Working plan
This contains:
- what variable you have measured;
- the equipment you used for the experiment;
- the setup you made (make a sketch or photo);
- precisely what you did:
  - What measurements did you carry out?
  - How have you processed the measurements (drawings/calculations)?
  - What calculations did you do (including the formulas)?

Section 3 Experimental results
This is where you can state what you observed or measured. This can be in textual form or as tables, graphs, photographs and so forth.

Section 4 Conclusions
The answer to the study question can be stated here. You also say what could have been done better.

A report should look good. It is not only about the information that your report contains: You must also present the content clearly and neatly. A number of useful pointers:
- Use A4 size paper.
- Make sure there is plenty of space at the margins: top and bottom, left and right.
- Choose an easily readable font at a large enough size.
- Put a heading in bold above each section. Then skip a line.
- Make sure that the drawings, tables and graphs are neat. Add a number to each so that you can refer to them in the text.

Glossary

A

air resistance luchtweerstandskracht
Weerstandskracht die ontstaat doordat een bewegend voorwerp de lucht voor zich opzij moet duwen.

alternating voltage wisselspanning
Spanning die voortdurend in een golfpatroon van plus naar min wisselt, zoals de spanning op het lichtnet.

B

biomass biomassa
Materiaal dat van planten en dieren afkomstig is en als energiebron wordt gebruikt.

body resistance lichaamsweerstand
De weerstand die je lichaam biedt aan een elektrische stroom (hoe groter de weerstand, des te kleiner de stroom).

C

calorific value stookwaarde
Warmte die vrijkomt als een bepaalde hoeveelheid brandstof wordt verbrand.

calorimeter warmtemeter
Apparaat waarmee je kunt meten hoeveel warmte nodig is voor het verwarmen van een bepaalde hoeveelheid water.

centre of gravity zwaartepunt
Een (denkbeeldig) punt waar je de zwaartekracht op een voorwerp kunt laten aangrijpen.

centripetal force middelpuntzoekende kracht
Kracht naar het middelpunt van een cirkelvormige of ellipsvormige beweging, waardoor het bewegende voorwerp voortdurend afbuigt en een baan volgt rond het middelpunt.

chemical energy chemische energie
Energie die in brandstoffen zit.

circuit breaker installatieautomaat
Een elektronische zekering. Als de zekering de stroom uitschakelt, klapt een hefboompje om.

coil spoel
Een spiraal van geïsoleerd koperdraad.

conduction geleiding
Proces waarbij warmte zich door een stilstaande stof heen verspreidt.

consuming electrical energy elektrische energie verbruiken
Het verbruiken van elektrische energie door elektrische apparaten (waarbij de elektrische energie wordt omgezet in andere soorten energie).

contact resistance contactweerstand
De weerstand op de plaatsen waar de stroom het lichaam in- of uitgaat (hoe groter de weerstand, des te kleiner de stroom).

convection stroming
Proces waarbij een vloeistof of gas in beweging komt en zo de warmte meeneemt.

D

directly proportional recht evenredig
Twee variabelen zijn recht evenredig als ze naar verhouding evenveel toenemen of afnemen: wordt de ene variabele n× zo groot of zo klein, dan wordt de andere ook n× zo groot of zo klein.

domestic system huisinstallatie
Een netwerk van elektriciteitsdraden dat door de muren en plafonds van een huis loopt: van de meterkast naar de stopcontacten en andere aansluitpunten.

double insulation dubbele isolatie
Manier van isoleren waarbij twee lagen isolatie worden aangebracht: rond de onderdelen waar de stroom doorheen loopt en aan de buitenkant van het apparaat.

dynamic equilibrium dynamisch evenwicht
Evenwicht dat zich na elke verstoring vanzelf opnieuw instelt, zoals het evenwicht tussen warmteproductie en warmteverlies in een woonhuis.

dynamometer krachtmeter
Instrument met een spiraalveer waarmee je krachten kunt meten.

E

earth leakage circuit breaker aardlekschakelaar
Voorziening die de stroomsterkte in de fasedraad vergelijkt met de stroomsterkte in de nuldraad. Als het verschil groter wordt dan 30 mA, dan schakelt de aardlekschakelaar de stroom uit. Er kan dan geen stroom meer weglekken.

earth wire aarddraad
Een koperdraad met groengeel gestreepte isolatie die de rand van het stopcontact verbindt met een pin die in de aarde is geslagen.

effective voltage effectieve spanning
De ‘gemiddelde’ spanning van een wisselspanning. Als je rekent met een wisselspanning, bijvoorbeeld om het vermogen uit te rekenen, gebruik je altijd de effectieve spanning.

efficiency rendement
De hoeveelheid energie die nuttig wordt gebruikt als percentage van het totaal aan energie dat wordt omgezet.

elastic deformation elastische vervorming
Vervorming waarbij de oorspronkelijke vorm weer terugkomt als de kracht ophoudt te werken.

electrical energy elektrische energie
Energie die door spanningsbronnen wordt geleverd, zoals batterijen en dynamo's.

electrical power elektrisch vermogen
1 De hoeveelheid elektrische energie per seconde die een centrale of turbine aan het netwerk levert.
2 De hoeveelheid elektrische energie per seconde die een apparaat uit het netwerk opneemt (en verbruikt).

electromagnet elektromagneet
Een elektrisch onderdeel, zoals een spoel, dat zich onder invloed van een elektrische stroom als een magneet gedraagt.

energy conversion energieomzetting
Proces waarbij de ene soort energie verandert in een andere soort energie.

energy flow diagram energiestroomdiagram
Schematische weergave van een energieomzetting.

energy loss energieverlies
Het gegeven dat er elektrische energie verloren gaat tijdens het transport, doordat een deel van die energie wordt omgezet in warmte.

energy meter energiemeter
Meter die het verbruik van elektrische energie in huis meet. De kWh-meter is zo genoemd omdat het verbruik wordt afgerekend in kWh (kilowattuur).

energy source energiebron
Alles wat een bruikbaar soort energie kan leveren.

energy transition energietransitie
De overgang van niet-duurzame energiebronnen naar duurzame, klimaatneutrale energiebronnen.

extension uitrekking
De afstand waarmee de lengte van een veer toeneemt als er een kracht op wordt uitgeoefend.

F

field line veldlijn
Lijnen die de richting van een magneetveld aangeven.

focus, foci brandpunt
Twee punten A en B die je nodig hebt om een ellips te kunnen tekenen. Voor alle punten P van de ellips geldt dat de som van de afstanden AP en BP steeds even groot is:
AP + BP = constant

force scale krachtenschaal
Verhouding die je kiest om krachten te kunnen tekenen. Geeft aan hoe groot de kracht is die 1 cm van de krachtenpijl voorstelt.

force kracht
Natuurkundig begrip dat duidelijk maakt hoe voorwerpen elkaars vorm en/of beweging veranderen.

fossil fuel fossiele brandstof
Een brandstof zoals aardolie, aardgas en steenkool, die is ontstaan uit de resten van planten en dieren.

free fall vrije val
Toestand waarin een voorwerp verkeert waar alleen de zwaartekracht op werkt. Een vrije val kan heel kort duren (als je ergens van af springt), maar kan ook eindeloos doorgaan (als je meereist met een ruimtestation in een baan rond de aarde).

frequency frequentie
Aantal keer dat het golfpatroon van de spanning zich per seconde herhaalt.

friction schuifweerstandskracht
Weerstandskracht die ontstaat doordat twee oppervlakken langs elkaar bewegen, zoals bij een ski die over de sneeuw glijdt.

frontal surface frontaal oppervlak
Het oppervlak van een voorwerp of een persoon recht van voren gezien.

G

generator generator
Onderdeel van een elektriciteitscentrale dat werkt als een grote dynamo: bewegingsenergie wordt ermee omgezet in elektrische energie.

geothermal heat aardwarmte
Warmte die uit diepe aardlagen afkomstig is.

gravity zwaartekracht
Kracht waarmee de aarde aan jou trekt en aan alle voorwerpen om je heen.

group fuse groepszekering
Voorziening die de stroom uitschakelt als de stroomsterkte in de groep hoger wordt dan 16 A.

group switch groepsschakelaar
Schakelaar waarmee je in één keer de spanning van alle stopcontacten en lichtpunten in een groep kunt halen.

H

heat warmte
Vorm van energie die de bewegingssnelheid van moleculen in een stof vergroot.

heat exchanger warmtewisselaar
Apparaat waarin warmte wordt overgedragen van de ene naar de andere stof.

heat source warmtebron
Apparaat dat warmte levert.

I

ideal transformer ideale transformator
Een denkbeeldige transformator waarin geen elektrische energie verloren gaat: het opgenomen vermogen is gelijk aan het afgestane vermogen.

induced voltage inductiespanning
Wisselspanning die met behulp van een veranderend magneetveld is opgewekt.

induction inductie
Het opwekken van een wisselspanning aan de uiteinden van een spoel met behulp van een veranderend magneetveld.

insulation isolatie
Maatregelen die je kunt nemen om het warmteverlies (van een woonhuis) te beperken.

K

kinetic energy bewegingsenergie
Energie die bewegende voorwerpen hebben als gevolg van het feit dat ze een snelheid hebben.

kWh meter kWh-meter
Meter die het verbruik van elektrische energie in huis meet. De kWh-meter is zo genoemd omdat het verbruik wordt afgerekend in kWh (kilowattuur).

L

law of conservation of energy wet van behoud van energie
Regel die stelt dat er bij een energieomzetting geen energie verloren gaat.

live wire fasedraad
Bruine elektriciteitsdraad waarop een wisselspanning van 230 V staat.

M

magnetic field magneetveld
Gebied waarin een magneet krachten uitoefent.

magnetic force magnetische kracht
Kracht die werkt tussen de twee polen van een magneet. Kan afstotend of aantrekkend zijn.

mains voltage netspanning
Spanning van effectief 230 V, zoals je die thuis gebruikt.

muscle strength spierkracht
Kracht die ontstaat doordat de spieren in een lichaam zich samentrekken.

N

neutral wire nuldraad
Blauwe elektriciteitsdraad die de stroomkring afmaakt. Op deze draad staat geen spanning.

Newton's First Law eerste wet van Newton
Een voorwerp waarop de resultante 0 N is, is in rust, of beweegt met een constante snelheid langs een rechte lijn.

normal force normaalkracht
Kracht die loodrecht vanuit het oppervlak van een voorwerp werkt. Bijvoorbeeld de kracht van een tafelblad op een fruitschaal.

O

overload overbelasting
Zo noem je het inschakelen van te veel apparaten in een groep waardoor de totale stroomsterkte boven 16 A komt.

P

parallelogram method parallellogrammethode
Manier om de resultante te vinden wanneer twee krachten een willekeurige hoek met elkaar maken.

plastic deformation plastische vervorming
Vervorming waarbij het voorwerp blijvend wordt vervormd nadat er een kracht op is uitgeoefend.

polarity polariteit
Aanduiding voor de richting van de spanning. Als de plus en min omwisselen (en de stroomrichting omdraait), verandert de polariteit van de spanning van positief in negatief.

power station elektriciteitscentrale
Centrale die grote hoeveelheden elektrische energie opwekt.

primary coil primaire spoel
Onderdeel van een transformator waar de elektrische energie uit het lichtnet in gaat. Er loopt wisselstroom doorheen.

Q

quality kwaliteit
Waarde. De kwaliteit van een energiesoort is de bruikbaarheid van die energiesoort.

quantity kwantiteit
Hoeveelheid.

R

radiant energy stralingsenergie
Energie van de straling die een voorwerp uitzendt, zoals de energie van het licht van de zon.

radiation straling
Proces waarbij warmte wordt verspreid door straling (kleine pakketjes stralingsenergie).

resilience veerkracht
Kracht die ontstaat als je een veerkrachtig materiaal uitrekt of indrukt.

resistance weerstandskracht
Kracht die weerstand biedt aan een beweging en de beweging daardoor tegenwerkt.

resultant resultante
De optelsom van alle krachten die op een voorwerp werken, waarbij je de krachten moet optellen als vectoren en niet als getallen.

rolling resistance rolweerstandskracht
Weerstandskracht die ontstaat doordat een rollend voorwerp en de ondergrond tijdens de beweging beide vervormen.

S

secondary coil secundaire spoel
Onderdeel van een transformator dat elektrische energie aan een apparaat afgeeft.

short circuit kortsluiting
Zo noem je een fout in een stroomkring waardoor de stroom een gemakkelijke weg vindt van fase- naar nuldraad, met een veel te kleine weerstand.

sliding resistance schuifweerstandskracht
Weerstandskracht die ontstaat doordat twee oppervlakken langs elkaar bewegen, zoals bij een ski die over de sneeuw glijdt.

soft iron weekijzer
Soort ijzer dat snel kan worden gemagnetiseerd en gedemagnetiseerd.

solar cell zonnecel
Onderdeel van zonnepanelen dat de stralingsenergie van zonlicht omzet in elektrische energie.

solar collector zonnecollector
Apparaat dat de stralingsenergie van zonlicht omzet in warmte, waarmee water wordt verhit.

specific heat soortelijke warmte
De hoeveelheid warmte die nodig is om 1 g van een stof 1 °C in temperatuur te laten stijgen.

spring constant veerconstante
Eigenschap van een veer die aangeeft hoe ver de veer uitrekt als er een kracht op wordt uitgeoefend.

supplying electrical energy elektrische energie leveren
Het afstaan van elektrische energie aan het elektriciteits-netwerk door centrales, windturbines, zonnepanelen, enzovoort.

switch wire schakeldraad
Zwarte elektriciteitsdraad die van een schakelaar naar een apparaat loopt en waar alleen spanning op staat als de schakelaar in de AAN-stand staat.

T

tensile force spankracht
Kracht die in een touw ontstaat als er aan beide uiteinden wordt getrokken.

transformer transformator
Apparaat dat een wisselspanning kan omzetten in een hogere of lagere wisselspanning met behulp van twee spoelen om een weekijzeren kern.

turbine turbine
Onderdeel van een elektriciteitscentrale dat bestaat uit een as, waaraan een groot aantal schoepen is bevestigd. Doordat er stoom tegen de schoepen spuit, komt de as van de turbine in beweging.

V

vector vector
Pijlvormige weergave van de grootte, de richting en het aangrijpingspunt van een kracht.

W

weight gewicht
Kracht die een voorwerp uitoefent op de ondergrond waar het op staat, als gevolg van de zwaartekracht op het voorwerp.

weightless gewichtloos
Toestand waarin een voorwerp geen gewicht ervaart, doordat het voorwerp nergens op steunt of aan ophangt.

wind turbine windturbine
Moderne windmolen die elektrische energie produceert.

Z

zero position nulstand
De lengte van een veer als die niet wordt uitgerekt.

Index

The page numbers after each concept tell you where it is explained in the lesson text and where it can be found in the course material overview. Concepts from the additional material only appear in the classroom text.

Acknowledgements

CONTENT DESIGN
Pointer grafische vormgeving
Crius Group

COVER DESIGN
Studio Struis

LAYOUT
Crius Group

AUTHORS
F. Alkemade
F. Kan
L. Lenders
S. Michon, michon educatie
F. Molin
R. Tromp
P. Verhagen

FINAL EDITING
C. Biemans, frontlinie.nl

TRANSLATION
Mike Wilkinson/Tessera Translations BV, Wageningen

TECHNICAL DRAWING
Sittrop Grafisch Realisatiebureau, Rotterdam;
Erik Eshuis, Groningen; Zanzara Illustrations, Gorleston

IMAGE RESEARCH
BenU

PICTURE AND PHOTO CREDITS
Aaron Amat/Shutterstock: p. 73 (b); ABB Group: pp. 45 (m), 57 (t), 58; Aleksandr Papichev/123RF: p. 166 (b); AlexLMX/Shutterstock: p. 26 (t); Angel Photography, Amsterdam: p. 29 (m); Anton Starikov/123RF: p. 48; Brian Donovan/Shutterstock: p. 101 (b); Canetti/iStockphoto: p. 145; Dafinchi/Shutterstock: p. 43; Didacus Odhiambo/Integrated Solar Cooking Project: p. 130; Don Mason/Blend Images LLC/Getty Images/Tetra images RF: pp. 64/65; Elmer van der Marel/De Beeldunie: p. 93; Erik Eshuis Infographics, Groningen: pp. 30, 38, 47, 49 (t), 97 (t/l), 97 (t/r), 122, 126, 128 (t, b), 133, 135, 137, 138 (t, b), 139 (t, b), 140 (t), 144 (b), 146, 148, 151, 153, 157, 159, 161; ESA/Anneke Le Floch: p. 102 (t); FirmaV/Shutterstock: p. 25; Flip Franssen/Hollandse Hoogte: p. 155; Flir: p. 144 (t); Ian Hodgson/Reuters/ANP Foto: p. 68; IsoBouw Systems BV, Someren: p. 149; Jeff Hinds/Shutterstock: p. 73 (t); Kirill Gorlov/AdobeStock: p. 15; Lars Kastilan/123RF/Sittrop Grafisch Realisatiebureau, Rotterdam: p. 87 (b); Liam West/Tesla: p. 165 (b); lightpoet/123RF: p. 172; malp/123RF: p. 164; mapraest/ Shutterstock: p. 141; Mark Bowden/iStockphoto: p. 35 (b); Mark Garlick/Science Photo Library/Hollandse Hoogte, The Hague: p. 89; maxim ibragimov/Shutterstock: p. 140 (b); Merlijn Michon Fotografie, Amsterdam: pp. 35 (t), 39 (b/l), 39 (b/r), 40, 49 (b), 53, 99 (b), 134, 177 (b); Merlijn Michon Fotografie, Amsterdam; Shutterstock: p. 33 (t); Michael Sohn/Associated Press/Hollandse Hoogte, The Hague: p. 101 (t); Michiel Wijnbergh/Hollandse Hoogte: p. 125 (m/r); Mike Bogemans/ Rijkswaterstaat: p. 11 (b); Mikkel Juul Jensen/Science Photo Library/ANP Foto, The Hague: p. 99 (t); Mischa Keijser/Getty Images/Cultura RF: pp. 120/121; NGK EUROPE GMBH : p. 165 (t); NurPhoto via ZUMA Press/ Hollandse Hoogte, The Hague: p. 114 (t); Olaf Krüger/ImageBroker/ Imageselect: p. 71 (b); Olena Z/Shutterstock: p. 115; pedrosala/ Shutterstock: p. 56; peepy/Shutterstock: p. 166 (t); Peter J. Segaar/www.polderpv.nl: p. 152; Pim Ras/Hollandse Hoogte, The Hague: p. 116; Prof. Bert Otten, Universiteit Groningen: p. 114 (b); Rudmer Zwerver/Shutterstock: pp. 16, 124; Ruud Morijn/Dreamstime: p. 21; Ruud Morijn/Nationale Beeldbank: p. 10; Sean Pavone/Shutterstock: p. 158; Serg64/Shutterstock: p. 28 (m/l); Shutterstock: p. 44 (b); Sittrop Grafisch Realisatiebureau, Rotterdam: pp. 8, 9, 12, 13, 17, 18 (t, b), 19, 20, 22 (b), 23, 26 (b), 28 (t), 28 (m/r), 29 (t), 31, 36 (t, b), 37, 39 (t), 41, 45 (t, b), 46, 50, 55, 66, 69 (b), 70, 71 (t), 72, 74 (t, b), 75 (t, b), 76, 77, 78 (t, b), 79, 80 (t, b), 81 (t, b), 82, 83, 84 (t, b), 85 (t, b), 86, 87 (t, b), 88, 91 (t, b), 94, 95 (b), 96, 97 (b), 100 (t, b), 102 (b), 103 (t/l, t/r), 104, 105, 106, 107 (t, b), 108, 109, 143, 154, 156, 177 (t), 183; Stroomversnelling: p. 147; Sopotnicki/Shutterstock: p. 6/7; T.W. van Urk/Shutterstock: p. 14; Tesla Motors Inc.: p. 29 (b); Tombow Pen & Pencil/www.tomboweurope. com: p. 69 (t); Ulrik Pedersen/Hollandse Hoogte, The Hague: p. 113; Vincent Jannink/ANP Foto: p. 57 (b), 90; vivooo/Shutterstock: p. 98; withGod/Shutterstock: p. 125 (m/l); Your Captain Luchtfotografie/ANP Foto, The Hague: p. 127; Zanzara Illustrations, Gorleston: pp. 11 (t), 22 (t), 32 (t, b), 33 (b), 42, 44 (t), 51, 111

COVER
Alexandre Eggermont/Getty images

ISBN 978 94 020 6515 2

Release 2020, first impression

MALMBERG